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# GEOLOGY AND MINERAL RESOURCES OF THE LEHIGHTON AND PALMERTON QUADRANGLES, CARBON AND NORTHAMPTON COUNTIES, PENNSYLVANIA

Jack B. Epstein
W. D. Sevon
J. Douglas Glaeser

COMMONWEALTH OF PENNSYLVANIA
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Arthur A. Socolow, State Geologist

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by **Jack B. Epstein**
U. S. Geological Survey

**W. D. Sevon**
Pennsylvania Geological Survey

**J. Douglas Glaeser**
The City College of the City
University of New York

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Dedicated to
Joseph F. Wietrzychowski
1931-1972

A co-worker in the initial stages of this study whose unique personality and perspective contributed significantly to its progress.

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# PREFACE

This report describes the nature and occurrence of rocks and unconsolidated surficial deposits present at and below the surface of a 112-square-mile area in Carbon, Lehigh, and Northampton Counties. The rocks are a diverse assemblage of limestones, dolomites, shales, siltstones, sandstones, and conglomerates, whereas the unconsolidated deposits consist mainly of glacial till, various gravels, and material in man-made dumps.

Each of the materials mapped in this area has its own characteristics which affect the way land and its resources may be utilized by man. In an area which is being subjected to continuing demands for proper land utilization, water supply, waste disposal, and resource availability, the information provided herein should be of value to planners, homesite developers, engineers, and water-well drillers.

To meet these needs, this report treats the thickness, lithology, engineering characteristics, and ground-water and mineral-resource potential of each of the distinct materials mapped in this part of Pennsylvania. Although these data and interpretations will serve as a guide to geologic problem solving, professional consultation may be desirable where costly decisions must be made.

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# GEOLOGY AND MINERAL RESOURCES OF THE LEHIGHTON AND PALMERTON QUADRANGLES, CARBON AND NORTHAMPTON COUNTIES, PENNSYLVANIA

by
Jack B. Epstein
W. D. Sevon
J. Douglas Glaeser

## ABSTRACT

The Lehighton and Palmerton 7½-minute quadrangles cover an area of about 112 square miles of diversified terrain in the folded Appalachian Mountain and Great Valley sections of the Valley and Ridge physiographic province in Carbon, Lehigh, and Northampton Counties, Pennsylvania. The Lehigh River and Blue Mountain are the prominent features of the topography. Rock units defined and mapped in the area are the lithified sediments that were deposited in a variety of offshore marine, marine shelf, marginal marine, and fluvial environments associated with two phases of basin filling. The rocks are separated into four lithotectonic units, each deformed semi-independently of adjacent lithotectonic units. Décollements presumably separate the lithotectonic units.

Lithotectonic unit 1 consists of about 12,000 feet of slate and graywacke of the Middle and Upper Ordovician Martinsburg Formation. This unit contains mainly asymmetric, similar, and nearly isoclinal folds, with wavelengths of 1,000 to 3,000 feet and amplitudes of 400 to 2,000 feet, formed mainly by passive flow and slip. Lithotectonic unit 2 includes about 3,100 feet of sandstone, siltstone, shale, and conglomerate of the Shawangunk Formation (Ordovician(?) and Silurian), Bloomsburg Red Beds (Silurian), and the lower part of the Poxono Island Formation (Silurian). This unit contains mainly asymmetric and concentric folds, with wavelengths of about one mile and amplitudes of 1,500 to 5,000 feet, formed by flexural slip with minor passive slip and flow. Lithotectonic unit 3 contains about 750 feet of limestone, shale, siltstone, sandstone, and dolomite of the upper part of the Poxono Island Formation, Bossardville Limestone, and Decker Formation (all Silurian), the Coeymans and New Scotland Formations, Shriver Chert, and Ridgeley Formation of the Oriskany Group

and the Schoharie-Esopus Formation (all Lower Devonian), and the Palmerton Formation and Buttermilk Falls Limestone (both Middle Devonian). This unit has asymmetric, concentric, similar, and flap folds, with wavelengths of 1,000 to 1,500 feet and amplitudes of about 1,550 feet, formed by flexural slip and flow and passive slip and flow. Lithotectonic unit 4 consists of more than 13,000 feet of sandstone, conglomerate, siltstone, and shale of the Middle Devonian Marcellus and Mahantango Formations, the Upper Devonian Trimmers Rock and Catskill Formations, the Devonian-Mississippian Spechty Kopf Formation, the Mississippian Pocono and Mauch Chunk Formations, and the Pennsylvanian Pottsville Formation. This unit contains nearly symmetric, concentric flexural-slip folds with wavelengths of more than five miles and amplitudes of about one mile.

Surficial deposits occur throughout the mapped area and include: Pleistocene pre-Illinoian(?) till and outwash(?), Illinoian(?) till and outwash, Wisconsinan outwash, shale-chip rubble, boulder fields, and colluvium; and Holocene alluvium, landslide deposits, and man-made dumps.

The rocks of the mapped area, except for the deeply weathered limestones, generally have good slope stability and foundation support strength, moderate to low primary infiltration capacity and aquifer potential but moderate to high secondary values for these properties, moderate resistance to weathering, and are moderately difficult to difficult to excavate. All of these properties are strongly influenced by the abundant bedding, cleavage, and joint partings of the rocks. Similar evaluations for the surficial deposits indicate less desirable values except for the ease of excavation of most of the unconsolidated materials.

Currently active and potential mineral resources are numerous in the Lehighton and Palmerton quadrangles and include slate, sand, paint ore, building stone, crushed rock, lightweight aggregate, clinker residue, clay, hydraulic cement, and roofing granules.

## INTRODUCTION

In 1960 a cooperative program of geologic investigation in northeastern Pennsylvania was begun by the Pennsylvania Geological Survey and the United States Geological Survey. This program was initiated because of (1) the lack of any detailed geologic information in northeastern Pennsylvania, and (2) the need for geologic information which has resulted from rapid development and increased interest in the economic mineral potential of the area. This report on the Lehighton and Palmerton 7½-minute quadrangles is a major product of this cooperative program and represents the basic framework upon which geologic investigations have continued in northeastern Pennsylvania.

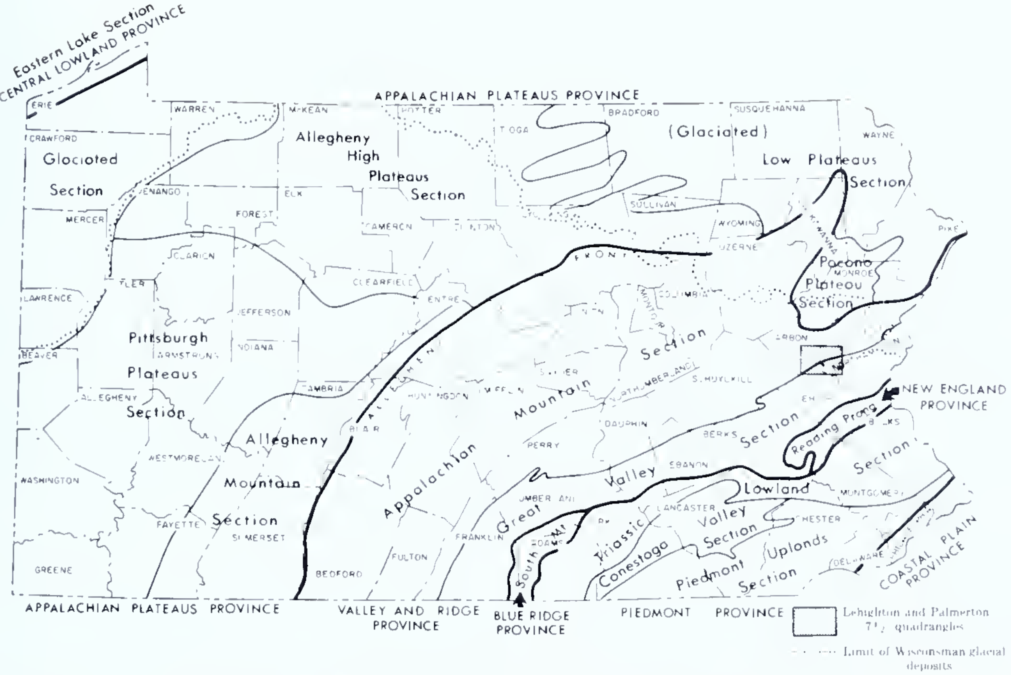

Figure 1. Physiographic provinces of Pennsylvania and location of Lehighton and Palmerton 7½-minute quadrangles.

The report area lies in parts of Carbon, Lehigh, Monroe, and Northampton Counties. Its location in the state is shown in Figure 1.

The Lehighton-Palmerton area was selected as the starting point for detailed work in northeastern Pennsylvania mainly because of the excellent exposures of parts of the Silurian rocks and almost all of the Devonian and Mississippian rocks along the Lehigh River. These exposures have been invaluable for the establishment of a sound stratigraphic framework for the area.

This report embodies the observations and interpretations of the three authors as well as the ideas of innumerable people who have visited the area during the years of investigation. The geologic investigation was initially divided at the base of the Oriskany Group and Epstein mapped and studied all of the rocks stratigraphically below the Oriskany Group as well as the surficial materials overlying those rocks. Glaeser and J. F. Wietrzychowski commenced investigation of the Oriskany and younger rocks, Wietrzychowski involving himself mainly with mapping the Palmerton quadrangle and Glaeser working on the stratigraphy of the Upper Devonian rocks. Wietrzychowski left the project in 1964 and was replaced by Sevon in 1965. Sevon mapped all of the Oriskany Group and younger rocks (revising much of Wietrzychowski's work) and the surficial materials overlying those rocks. Thus, the map represents basically the work of Epstein and Sevon, and the report is divided principally as follows: Epstein, all of the stratigraphy below the Oriskany Group, most of the structure section, and part of the surficial geology, environmental geology, and mineral resources sections; Glaeser, the stratigraphy of the Trimmers Rock and Catskill Formations; Sevon, the stratigraphy of the Oriskany Group through the Mahantango Formation, the Spechty Kopf, Pocono, Mauch Chunk, and Pottsville Formations, most of the environmental geology and mineral resources sections, and part of the surficial geology and structure sections.

## ACKNOWLEDGEMENTS

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## PHYSICAL SETTING

The dominant topographic feature of the mapped area is Blue Mountain, a long, narrow ridge which trends west-southwest across the southern part of the area, reaches altitudes generally over 1,400 feet, and has local relief of about 1,000 feet. This mountain marks the southern limit of the folded Appalachian Mountain section of the Valley and Ridge physiographic province. The Great Valley section of the same province lies to the south of Blue Mountain and the Pocono Plateau section of the Appalachian Plateaus physiographic province lies immediately to the north of the area.

The second most important geomorphic feature in the area is the valley occupied by the Lehigh River. Except for short reaches south of Jim Thorpe and west of Palmerton where the river parallels the regional trend of bedrock, the course of the Lehigh River flows nearly perpendicular to the regional trend of bedrock. The river has cut through very resistant rock materials to form a spectacular gorge south of Jim Thorpe and the equally spectacular Lehigh Gap south of Palmerton. These features have led to the speculation that the river has been superimposed upon the underlying bedrock from an old peneplane surface such as the Schooley, but Epstein (1966) suggests that the location of the Lehigh Gap is a function of structural weakness and not necessarily related to superimposition. The Lehigh River is the main stream into which all surface water of the area drains.

The area south of Blue Mountain consists of gently rolling hills with local relief of 100 to 200 feet. The area has some surficial materials on the surface, but most of the drainage cuts into shale of the Martinsburg Formation. There appears to be no relationship between drainage pattern and the complexly folded Martinsburg. This lack of relationship between structure and drainage, and the general accordance of many hilltop elevations in this and adjacent areas, has led to the suggestion that the hilltops represent the remnants of a former erosion surface generally designated the Harrisburg peneplane (Ver Steeg, 1934).

Blue Mountain is part of a continuous mountain ridge extending from New York (to the northeast) to Maryland (to the southwest), broken only occasionally by water gaps formed by major streams such as the Lehigh River. The crest of the mountain is underlain by resistant upturned rocks; the slopes are steep and in places covered with thick colluvial deposits which have not been removed by streams at the slope base. The two wind gaps, Lehigh Furnace Gap and Little Gap, may represent the former positions of major streams, which once flowed through Blue Mountain when topography was regionally at the general level of the base of the wind gaps, and which were subsequently pirated by tributaries to the Lehigh River.

Between Blue Mountain on the south and Mauch Chunk Ridge and Bear Mountain (and its eastward continuation) to the north, there are a variety of hills, valleys, ridges, and drainage systems which reflect almost perfectly the underlying bedrock geology. Ridges such as Stone Ridge (southwest of Bowmanstown), Stony Ridge (east of Palmerton), Mahoning Hills (southwest of Lehighton, and their continuation to the northeast through Harrity and Forest Inn) and Indian Hills (southeast of Lehighton) result from differential erosion of less resistant rocks on either side of more resistant rocks. The main tributaries to the Lehigh River, such as Lizard, Mahoning, Pohopoco, and Aquashicola Creeks, parallel the regional trend of bedrock, whereas tributaries to these streams cut across bedrock and are in turn joined by drainage which parallels bedrock. The resultant topography, developed through erosion by the drainage network, reflects very well the regional bedrock trends and relative resistance of the rocks to erosion.

Few drainage anomalies occur within this part of the area but two should be mentioned. The course of Pohopoco Creek between its mouth at Parryville and Harrity is anomalous with respect to the general orderliness of drainage patterns elsewhere in the area; this part of the stream occupies a gorge, whereas east of Harrity the stream valley is relatively broad. The narrow part of the channel may have resulted from cutting during the Illinoian(?) glaciation. However, in view of the amount of downcutting required to create a graded stream, cutting during a pre-Illinoian(?) glaciation (which is suggested by some deposits south of Lehigh Gap) seems more probable.

Mauch Chunk Ridge and Bear Mountain represent the southwestward extension and actual beginning of the Pocono Plateau escarpment. This ridge is upheld by very resistant uppermost Catskill rocks and is the most striking topographic feature in the northern part of the area.

# STRATIGRAPHY

This section treats the physical description of the various lithologic units, both bedrock and surficial, which have been identified, studied, and mapped in the Lehighton and Palmerton quadrangles. The emphasis is placed entirely upon the physical aspects of these units with minimal discussion of stratigraphic nomenclature. The stratigraphic nomenclature used for rock units in the mapped area is reviewed in Plate 3.

The rock sequence in the Lehighton and Palmerton quadrangles consists of about 27,000 feet of shale, siltstone, sandstone, conglomerate, limestone, and dolomite ranging from Late Ordovician to Pennsylvanian in age. Several of the stratigraphic units are poorly exposed because of deep weathering and cover by colluvium, alluvium, and glacial deposits. Large areas of the Martinsburg Formation are covered, and, for the same reason, stratigraphic details of the upper part of the Bloomsburg Red Beds, up to and including the Shriver Chert of the Oriskany Group, are poorly known. However, data from exposures in railroad cuts, abandoned quarries, and other excavations reported in the literature have established a reliable stratigraphic succession. Because several of the units are very deeply weathered, satisfactory descriptions of the fresh rock cannot be made in the quadrangles. The Devonian and Mississippian stratigraphic units are almost completely exposed along the Lehigh River and much information has come from detailed descriptions of these exposures.

## ORDOVICIAN

### Martinsburg Formation

The name Martinsburg was first used by Geiger and Keith (1891), and the formation was first adequately described by Keith (1894) for partly calcareous shales exposed near Martinsburg, West Virginia. The belt of rock was traced by subsequent workers into the Lehigh and Delaware Valleys, where it consists of slate and graywacke 9,800 to 12,800 feet thick, where it is generally considered to be Middle Ordovician (Trentonian) to Late Ordovician (Maysvillian) in age, and where it has been divided into three members (summarized by Drake and Epstein, 1967).

For nearly a century there has been disagreement on the internal division of the Martinsburg Formation in eastern Pennsylvania. On the basis of faunal and structural evidence in the area generally west of the Lehigh River, the Martinsburg was divided into two groups: a lower shale unit and an upper sandstone unit (Stose, 1930; Ward, 1937; Willard and Cleaves, 1939; Miller and others, 1941; Willard, 1943; and Moseley, 1950). Between the Delaware and Lehigh Rivers, structural evidence suggests that the Martinsburg consists of two slate belts separated by a middle sandstone-bearing unit (Merriman, 1898; Dale and others, 1906, 1914; Peck, 1908; Miller, 1925; Behre, 1924, 1933; and Miller and others, 1939). Behre's work is the most detailed, but his threefold interpretation was not accepted on the most recent State geologic map (Gray and others, 1960). Detailed stratigraphic and structural evidence reported by Drake and Epstein (1967) shows that the Martinsburg of the slate belt can be divided into three members in almost the same way as defined by Behre. These are, in ascending order, the Bushkill, Ramseyburg, and Pen Argyl Members.

Those who believe in a twofold division of the Martinsburg have estimated that the formation is as thin as 3,000 feet (Stose, 1930), whereas those who believe in three members have estimated thicknesses in excess of 10,000 feet (Behre, 1933; Drake and Epstein, 1967).

All geologists agree that a basal slate member (Bushkill) is overlain by a sandy member (Ramseyburg). Those who believe in two members maintain that the uppermost member (Pen Argyl) of the "threefold school" is actually the lower member repeated by folding and that it dips *underneath* the middle member in a large upright regional syncline. However, in the Lehighton and Palmerton quadrangles and east to the Delaware River, where the Pen Argyl dips south at its contact with the Ramseyburg, it is overturned, as indicated by graded beds and crossbeds, bedding-cleavage relations, and geometry of folds. Where the contact dips to the north, the beds are upright, as shown by sedimentary structures, and the Pen Argyl is clearly younger than the Ramseyburg.

There is also supporting stratigraphic evidence. If the upper member were the lower member repeated by folding, the two units should be lithically similar. However, the Pen Argyl and Bushkill Members are lithically distinct. In addition, quarrymen in eastern Pennsylvania have long been aware of two distinctly different slate belts in eastern Pennsylvania: a "soft-vein" belt to the north and a "hard-vein" belt to the south. These are not belts repeated by folding; Stose's (1930) regional syncline does not exist in this area (Drake and Epstein, 1967).

In the Lehighton and Palmerton quadrangles, only the Pen Argyl and Ramseyburg Members are exposed. The Bushkill Member crops out to the south.

### *Ramseyburg Member*

The Ramseyburg Member of the Martinsburg Formation was named for representative outcrops near Ramseyburg, Warren County, N.J. It consists mostly of slate but is characterized by interbedded graywacke that makes up about 20 to 30 percent of the unit. The beds of slate are less than 1 inch to more than 10 feet thick. The graywacke consists of medium-gray (N5)[1] siltstone to medium-grained sandstone in beds ranging from laminae to more than 4 feet in thickness. Graywacke beds are generally poorly exposed because they are calcareous (see following section on petrography) and readily leached. Characteristically, these beds hold up low hills and litter the ground with "tobacco-brown" (light-brown (5YR5/6) to moderate-yellowish-brown (10YR5/4)) angular fragments several inches long. Commonly, the bottoms of graywacke beds are abrupt and cut into underlying beds. The graywackes grade up into medium-gray slate which in turn passes into grayish-black (N2) carbonaceous slate. Graded bedding, parallel and ripple laminations, convoluted bedding, and sole marks are common features in the graywacke. A few beds contain comminuted fossil debris, mostly brachiopods and crinoids. These features, along with regional paleogeographic considerations, led McBride (1962) to the conclusion that the graywackes were emplaced by turbidity currents in deep water where the "normal" sediment was pelagic mud.

To the east, in the Bangor-Wind Gap area, slate "runs" within the Ramseyburg are presently quarried and have been extensively quarried in the past. In the Palmerton quadrangle, no quarries are active at present.

The Ramseyburg is about 2,700 to 3,000 feet thick, an estimate based on construction of cross sections. Its gradational contact with the underlying Bushkill Member of the Martinsburg Formation is exposed south and east of the Lehighton and Palmerton quadrangles, where it is placed at the base of the lowest graywacke bed that is generally more than 1 foot thick.

### *Pen Argyl Member*

The slate quarries near Pen Argyl, Northampton County, Pennsylvania, are the type locality for the Pen Argyl Member of the Martinsburg Formation (Drake and Epstein, 1967). In the Palmerton and Lehighton quadrangles, the Pen Argyl is about 5,000 to 6,000 feet thick. It is unconformably overlain by the Shawangunk Formation, so its total thickness could be greater. The Pen Argyl consists of medium-dark-gray (N4) and dark-gray (N3), thin- to thick-bedded, evenly bedded, calcareous slate rhythmically interbedded with grayish-black (N2) carbonaceous slate (Figure 2). In some exposures, graywacke laminae and beds that may be as much as 4 feet thick mark the base of fining-upward sequences as they do in the underlying Ramseyburg Member. The weathered slate is generally color banded (for example, moderate brown (5YR3/4), moderate-orange pink (5YR8/4), light-olive gray (5YR6/1), and grayish

---

[1] All rock colors were determined using the *Rock-color chart* (Goddard and others, 1948).

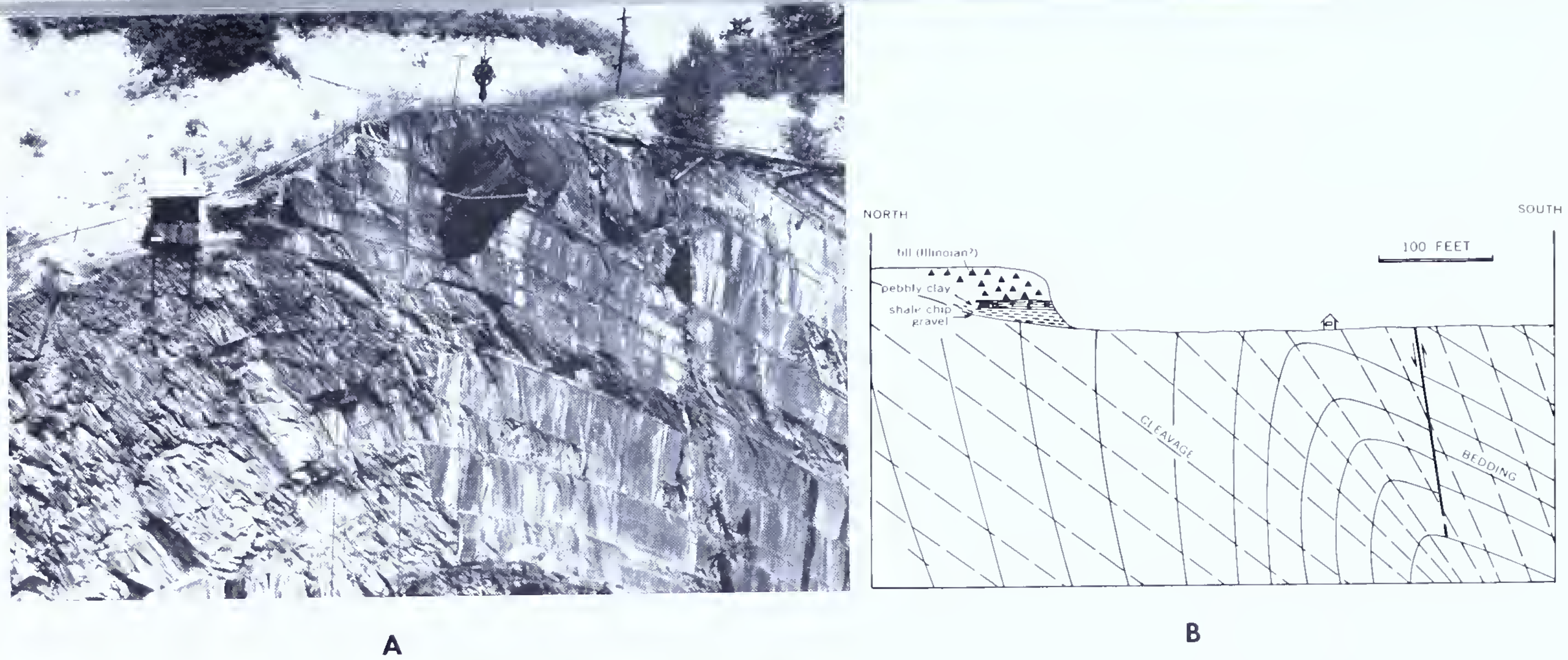


Figure 2. A. Thick-bedded slate in the Pen Argyl Member of the Martinsburg Formation, quarry of Penn Big Bed Slate Company, 6,000 feet west of Rextown and 300 feet south of the Lehighton quadrangle, in the Slatedale quadrangle. View looking to the northeast. Cleavage dips 55SE in the axial plane but fans the fold on the limbs of the overturned anticline (compare with Figure 2B). The thickest bed in the quarry, the Penn Big Bed, seen in the photograph, is 12 feet thick measured perpendicular to bedding and 21 feet thick measured along the "split" or cleavage. The rock is cyclically bedded, medium-gray slate grading up into grayish-black carbonaceous slate. Thinner beds of graywacke with convolutions form the base of some of the cycles. Note the steeply dipping fault on the gently dipping southeast limb of the fold. Also note the glacial deposits overlying the slate. The Penn Big Bed is the only active slate quarry in this part of the Lehigh Valley. B. Geologic section of the Penn Big Bed Slate Company quarry showing structure in the Pen Argyl Member of the Martinsburg Formation and the overlying Illinoian(?) till.

orange (10YR7/4)). The lower contact of the Pen Argyl is the top of the uppermost prominent graywacke of the Ramseyburg Member. Many beds in the Pen Argyl are more than 10 feet thick, and some are as much as 25 feet thick. This is the major difference between the Pen Argyl and the Bushkill Member which underlies the Ramseyburg—beds in the Bushkill are generally not more than 1 inch thick and are not known to exceed 6 inches.

### *Petrography*

The slates and sandstones (graywackes), aside from the gross lithic differences mentioned above, vary little throughout the Martinsburg Formation. Grain size ranges from less than .005 mm in clay slates to about 0.3 mm in medium-grained sandstones.

As determined by semiquantitative X-ray diffraction analyses, using the method of O'Neill and others (1965) and the limits of accuracy that they suggest, the dominant minerals in six random samples of slate in the Palmerton quadrangle are quartz (32-45 percent), muscovite (25-54 percent), chlorite (13-32 percent), and feldspar (1-3 percent). Calcite is variable, as seen in thin section. Probably much of the calcite is ankeritic, judging from the brown stain that forms on weathering. Pyrite and black opaque minerals are commonly scattered throughout all samples. The grayish-black (N2) slates that form the top of upward-fining cycles are carbonaceous, and finer grained and less calcareous than the dark-gray slates.

Quartz grains in the slate are angular. They are elongate in the direction of cleavage, and the sides that are perpendicular to cleavage are ragged, evidently because of pressure solution. Finer grained quartz, chlorite, muscovite, calcite, and iron-oxide dust have grown in the pressure-shadow areas (Figure 3).

Chlorite and muscovite form a large part of the finer interstitial minerals of the slate. They are lath shaped, and some of these grains are parallel to the cleavage, although many grains are not. Larger grains of intergrown chlorite and muscovite are more than 10 times the average grain size of the interstitial minerals and are believed to be porphyroblasts (Figure 3). The chlorite has blue and reddish-brown interference colors and is identified as pennine.

Carbonaceous matter forms black streaks in cleavage planes. A sparse grain of microcline can be identified in thin section, but the dominant feldspar is albite, as indicated by X-ray analysis. Albite has not been definitely identified in thin section because of the fine grain size of the slates.

Chemical analyses of typical slates and graywackes from the Martinsburg Formation are given in Table 1. The relatively low silica content,

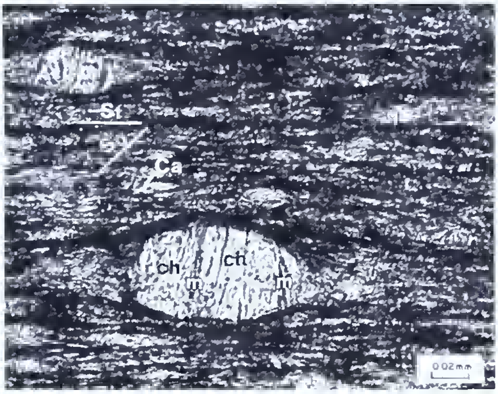


Figure 3. Photomicrograph (plane-polarized light) of medium-dark-gray (N4) slate, Pen Argyl Member of the Martinsburg Formation, abandoned Peters quarry, 4,900 feet N19E of Walnutport, Pennsylvania, Palmerton quadrangle. Bedding ($S_0$), not apparent in photograph, is at an angle of 44° to slaty cleavage ($S_1$). Several large grains of intergrown chlorite (ch) and muscovite (m), believed to be porphyroblasts, are as much as 15 times the average grain size of groundmass muscovite, chlorite, and quartz. These grains are elongated in the direction of slaty cleavage, their mineral cleavage is at a high angle to the slaty cleavage, and the mineral cleavage is at an appreciable angle to bedding. Most platy minerals are parallel to the slaty cleavage, but some, not readily apparent in this photomicrograph, are not. Quartz (q) is ragged with growths of smaller muscovite, quartz, chlorite, and calcite in pressure-shadow areas (arrow). Opaque minerals, mostly pyrite and probably magnetite, and calcite (ca) are scattered throughout. Chemical analysis of this rock is given in Table 1, sample 2.

low silica/alumina ratios, and low alumina/soda ratios, as well as the textural and mineralogical characteristics of these rocks, particularly the sandstones, show that they are an immature suite (compare with more mature rocks of the Shawangunk Formation in Table 2). Further details of mineralogy and chemical composition have been given by Behre (1933).

The graywacke in the Martinsburg Formation is hard, medium-gray (N5) to medium-dark-gray (N4), micaceous, chloritic, poorly sorted sandstone and siltstone. Both lithic and feldspathic graywackes are common (classification of Pettijohn, 1957). As shown in thin section (Figures 4-6), the matrix consists predominantly of silt- and clay-sized muscovite, quartz, chlorite, and calcite, with minor opaque minerals and carbonaceous matter. Floating in the matrix, which ranges from about 25 to 50 percent of the rock, are angular grains of quartz (probably 30 to 40 percent), feldspar (1-10 percent, predominantly plagioclase and mostly albite-andesine), muscovite and chlorite (probably averaging about 5 percent), and calcite (probably 1 to 15 percent). The calcite in many thin sections appears to be detrital because it occurs as discrete irregular grains with the same range in grain size as detrital quartz and does not generally

## Table 1. *Chemical and Semiquantitative Spectrographic Analyses of Slate (Samples 1 and 2), Silty Slate (Sample 3), and Graywacke (Samples 4 and 5) from the Martinsburg Formation*

Analysis of sample 1 is from Dale and others, 1914, p. 108. Values for samples 2-5 above the double line are from rapid-rock analyses by P. Elmore, G. Chloe, J. Kelsey, S. Botts, H. Smith, J. Glenn, and L. Artis, U.S. Geological Survey. Values, in parts per million, for samples 2-5 below the double line are from semiquantitative spectrographic analyses by J. L. Harris, U.S. Geological Survey, analyst. N, not detected or at limit of detection; L, detected but below limit of determination. The following elements were looked for in samples 2-5 and not detected or were found in amounts at the limit of detection: As, Au, Bi, Cd, Eu, Ge, Hf, In, Li, Mo, Nd, Pd, Pr, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, U, W, Zn.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ | 56.38 | 50.2 | 66.1 | 69.9 | 59.2 |
| $Al_2O_3$ | 15.27 | 16.4 | 15.2 | 12.7 | 8.4 |
| $Fe_2O_3$ | 1.67 | 2.0 | 1.4 | 2.0 | 1.5 |
| FeO | 3.23 | 4.4 | 4.2 | 4.1 | 3.2 |
| MgO | 2.84 | 2.8 | 2.7 | 2.4 | 2.6 |
| CaO | 4.23 | 7.6 | .17 | .36 | 9.6 |
| $Na_2O$ | 1.30 | .63 | .48 | 1.3 | 1.5 |
| $K_2O$ | 3.51 | 3.8 | 3.3 | 2.6 | 1.5 |
| $H_2O-$ | .77 | .19 | .47 | .29 | .10 |
| $H_2O+$ | 4.09 | 3.8 | 4.0 | 3.0 | 1.6 |
| $TiO_2$ | .78 | .80 | .94 | .84 | .48 |
| $P_2O_5$ | .17 | .16 | .12 | .15 | .12 |
| MnO | .09 | .10 | .07 | .05 | .17 |
| $CO_2$ | 3.67 | 6.6 | .08 | .05 | 9.5 |
| Total (percent) | 100.39[a] | 99.5 | 99.2 | 99.74 | 99.5 |
| Ag | | N | N | N | 1 |
| B | | 70 | 50 | 30 | 30 |
| Ba | | 700 | 300 | 200 | 200 |
| Be | | 3 | 2 | 1 | 1 |
| Co | | 20 | 15 | 15 | 10 |
| Cr | | 70 | 70 | 50 | 30 |
| Cu | | 30 | 20 | 30 | 15 |
| La | | 100 | 70 | N | N |
| Nb | | 10 | 20 | 10 | 7 |
| Ni | | 50 | 50 | 30 | L |
| Pb | | 1 | 2 | N | 5 |
| Sc | | N | N | N | 7 |
| Sr | | 300 | 15 | 50 | 300 |
| V | | 100 | 150 | 70 | 50 |
| Y | | 50 | 30 | 30 | 20 |
| Zr | | 100 | 200 | 200 | 150 |
| Ce | | 500 | 300 | 100 | 100 |
| Ga | | 20 | 15 | 15 | 10 |
| Yb | | 5 | 3 | 3 | 2 |

## Table 1. (*Continued*)

1. Slate, Pen Argyl Member, "Lower Franklin bed," abandoned Old Franklin quarry, 1,900 feet southeast of Rextown, Slatedale quadrangle, 1,000 feet south of Lehighton quadrangle, Lehigh County, Pa. Note: a, includes BaO (0.08 percent), $FeS_2$ (1.72 percent), and C (0.59 percent).
2. Slate, Pen Argyl Member, 4,900 feet north-northeast of Walnutport, Palmerton quadrangle, Northampton County, Pa. Figure 3 is a photomicrograph of sample.
3. Silty slate, Pen Argyl Member, 233 feet stratigraphically below contact of Shawangunk Formation and Martinsburg Formation along abandoned Lehigh and New England Railroad grade at Lehigh Gap, Palmerton quadrangle, Northampton County, Pa.
4. Graywacke from 3-foot-thick bed, Pen Argyl Member, 152 feet stratigraphically below contact of Shawangunk Formation and Martinsburg Formation along abandoned Lehigh and New England Railroad grade at Lehigh Gap, Palmerton quadrangle, Northampton County, Pa. Figure 5 is photomicrograph of sample.
5. Graywacke, Pen Argyl Member, abandoned Lehigh Gap slate quarry, 4,500 feet north of Slatington, Palmerton quadrangle, Lehigh County, Pa. Figure 4 is photomicrograph of sample.

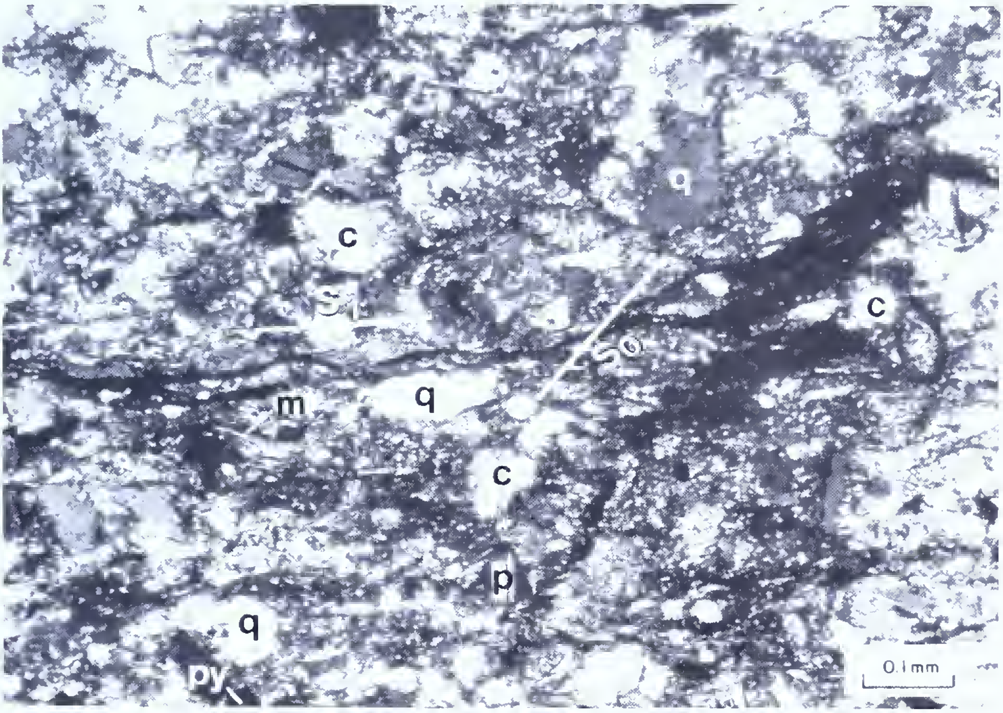


Figure 4. Photomicrograph (crossed polarizers) of medium-dark-gray, fine- to medium-grained lithic (calcitic) graywacke, Pen Argyl Member of the Martinsburg Formation, abandoned Lehigh Gap slate quarry, 4,500 feet north of Slatington, Pa., Palmerton quadrangle. The framework grains are as much as 0.2 mm long and consist of quartz (q, 35 percent); irregular discrete grains and lesser rhombs of calcite (c, 15 percent); plagioclase (p, 1 percent); muscovite (m) and chlorite (about 2 percent); and sparse zircon (z). The groundmass is composed of finer grained muscovite, quartz, chlorite, and calcite, and lesser carbonaceous matter and opaque minerals such as pyrite spherules (py). Note cleavage ($S_1$) which is at an angle of 25° to bedding ($S_0$). Chemical analysis of this sample is given in Table 1, column 5.

envelop and form a cement around other grains. Thus, if the calcite grains are rock fragments, these sandstones are lithic graywackes (Figure 4). Rock fragments of other types, such as shale and siltstone, are rare in calcitic graywackes and common in some noncalcitic types (Figure 5). Feldspathic graywackes are also common (Figure 6). Heavy minerals, such as zircon, tourmaline, and rutile, were noted. No amphibole or pyroxene was seen. Biotite is not abundant but generally can be found. In outcrop, intraclasts of shale (now slate) are common. These are as much as several inches long. Many graywacke beds have framework minerals that are dominantly silt size and generally overlie graywacke sandstones and grade up into slates.

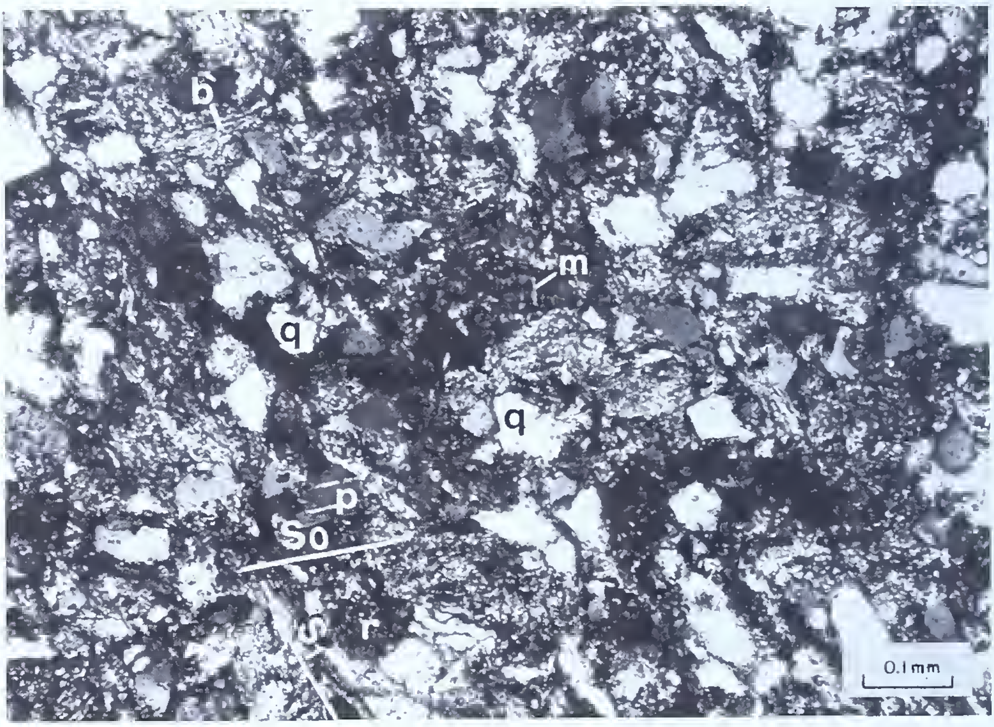


Figure 5. Photomicrograph (crossed polarizers) of lithic graywacke, Pen Argyl Member of the Martinsburg Formation, 152 feet below the contact with the Shawangunk Formation, Lehigh Gap, Palmerton quadrangle, Pennsylvania. The framework minerals are quartz (q, 34 percent), argillite rock fragments (r, 9 percent), plagioclase (p, 4 percent), and microcline (m) and orthoclase (2 percent), in a fine-grained matrix of muscovite, quartz, and chlorite (47 percent) with minor limonite and other opaque minerals. Detrital biotite (b), whose long dimension is parallel to bedding and which is partly altered to chlorite, makes up less than 1 percent of the rock. Bedding ($S_0$) makes an angle of 60° to cleavage ($S_1$). Chemical analysis of this sample is given in Table 1, column 4.

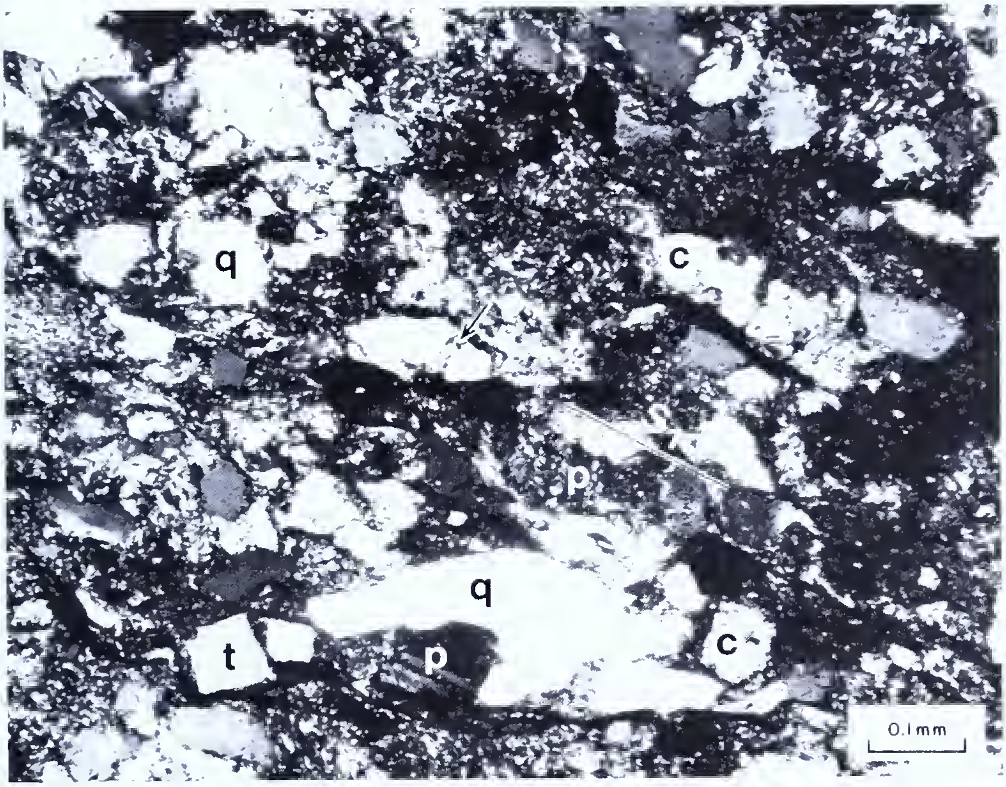


Figure 6. Photomicrograph (crossed polarizers) of fine-grained feldspathic graywacke, upper part of the Ramseyburg Member of the Martinsburg Formation, roadcut along Pa. Route 145, Walnutport, Pa., 1,200 feet south of the Palmerton quadrangle in the Cementon quadrangle. Matrix (about 50 percent) consists of a paste of muscovite, chlorite, quartz, calcite, and opaque matter. The framework grains are quartz (q, 40 percent), feldspar (mostly plagioclase, p, 3 percent), and calcite (c, 7 percent). The quartz grains are rutilated in part and are generally single grains with straight to slightly undulose extinction, although some grains are semicomposite. Minor amounts of large grains of muscovite and chlorite, rock fragments (shale and chert), as well as grains of biotite, subhedral zircon, and angular tourmaline (t) are also found. Some calcite appears as discrete grains, but much is recrystallized and envelops other grains. Note growth of muscovite between quartz grains (arrow) parallel to cleavage ($S_1$).

### *Age*

The Martinsburg Formation in eastern Pennsylvania grades down into the Jacksonburg Limestone. The top of the Jacksonburg is late Middle Ordovician in age (Rocklandian to Shermanian of Sweet and Bergström, 1971) on the basis of conodont studies by Barnett (1965) and confirmed by conodont collections of J. B. Epstein which were identified by J. W. Huddle (written commun., 1970). The upper age limit of the Martinsburg is generally given as early Maysvillian (Twenhofel and others, 1954) on the basis of an abundant shelly fauna initially described by

Ulrich (in Stose, 1930, p. 648-649) from the Schochary Ridge area about 8 miles southwest of the Lehighton quadrangle. This age assignment has generally been adhered to (Behre, 1924, 1933; Willard, 1939, 1943; Moseley, 1950; Bretsky and others, 1969; McIver, 1970).

Graptolites were collected in the upper half of the Pen Argyl Member from four localities on the east side of the Lehigh River between the contact with the Shawangunk Formation and one mile to the south. At all the fossil localities, the rock breaks parallel to bedding, either because cleavage is absent or poorly developed or because bedding and cleavage are almost parallel. In general, most of the graptolites are dark brown and contrast with the lighter colored weathered slate. These graptolites confirm that the age of the youngest beds exposed at Lehigh Gap is early Late Ordovician (Edenian to early Maysvillian or upper subzone of graptolite zone 13). The faunal list, localities, and discussion of the graptolites are given by Epstein and Berry (1973).

## ORDOVICIAN(?) AND SILURIAN

### Shawangunk Formation

Mather (1840) named the Shawangunk Grit for sandstones and conglomerates in southeastern New York that are part of the same outcrop belt as rocks in eastern Pennsylvania called Levant by Rogers (1858) and Oneida and Medina by White (1882). The term Shawangunk Conglomerate was first used by Grabau (1909) for these rocks in eastern Pennsylvania. The lithic name was changed from conglomerate to formation in the Delaware Water Gap area by Drake and others (1969). Schuchert (1916) and Swartz and Swartz (1931) gave an account of the early nomenclatural development of the Shawangunk.

The Tuscarora Sandstone and Clinton Formation were traced from central Pennsylvania eastward to Lehigh Gap by Swartz and Swartz (1931). Further east, according to them, these units lose their identity and merge into the Shawangunk Formation. Recent detailed mapping has shown that the Clinton Formation of Swartz and Swartz (1931) can be traced eastward from the Lehigh Gap area to Delaware Water Gap (Figure 7), where it forms a tongue in the Shawangunk (Epstein and Epstein, 1967, 1969, 1972; Drake and others, 1969; Epstein, 1971, 1973). The sandstones and conglomerates that were called Tuscarora by Swartz and Swartz can similarly be traced beneath the Clinton. Because the name Shawangunk has priority over both the Tuscarora (named by Darton and Taff in 1896) and Clinton (named by Conrad, 1842), the Shawangunk Formation was used by Epstein and Epstein (1972) in the area between the Lehighton and Palmerton quadrangles and Delaware

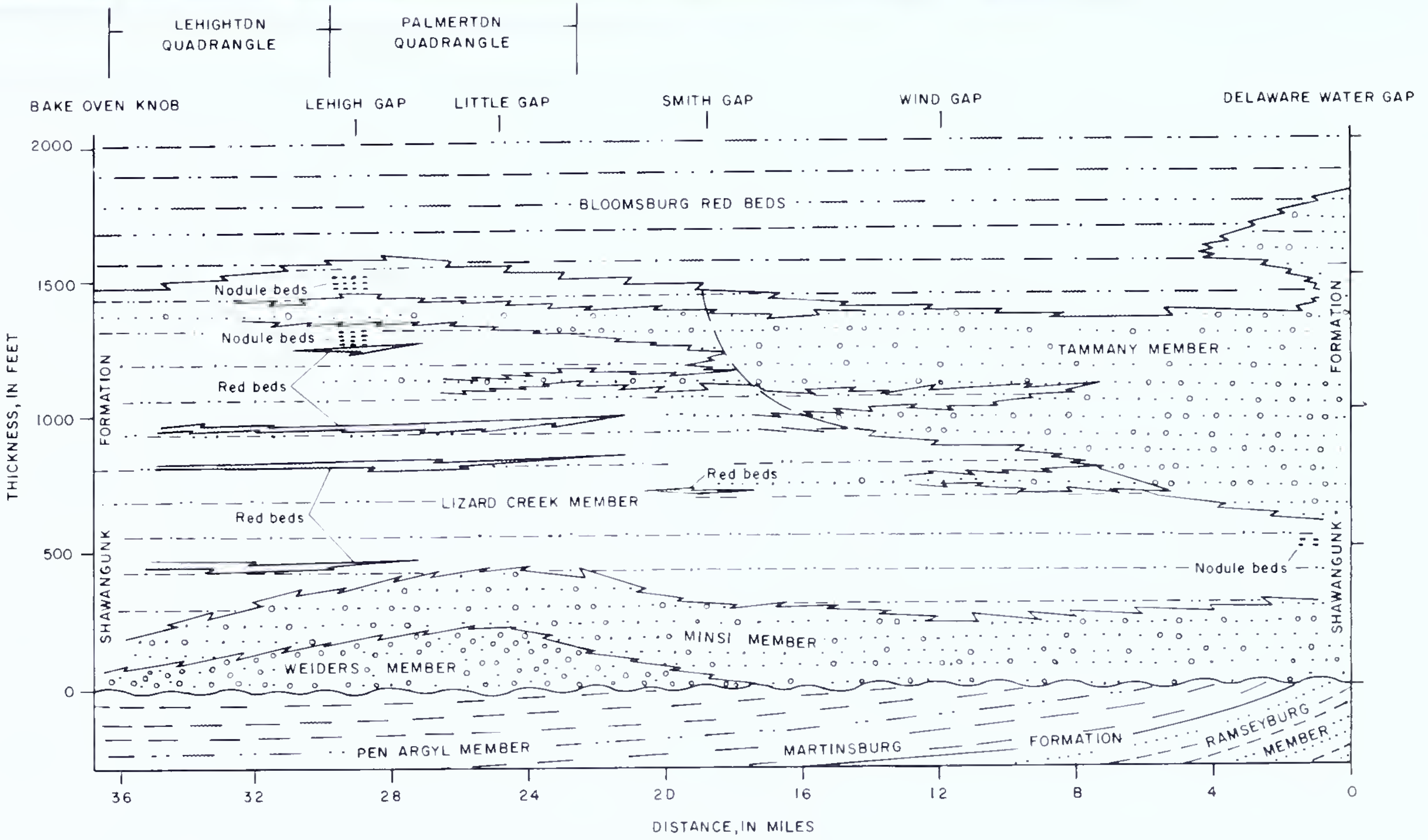


Figure 7. Section showing stratigraphic relations of the Shawangunk Formation in the Lehighton and Palmerton quadrangles and in easternmost Pennsylvania (from Epstein and Epstein, 1972).

Water Gap for rocks above the Martinsburg Formation and below the Bloomsburg Red Beds, and the names Clinton and Tuscarora were abandoned.

Four distinct lithic assemblages in the Shawangunk Formation have been mapped in eastern Pennsylvania. These were defined as members by Epstein and Epstein (1972) and include, in general ascending order, the Weiders, Minsi, Lizard Creek, and Tammany Members (Figure 7). The Tammany Member pinches out near Smith Gap and does not extend westward into the Palmerton quadrangle.

The Shawangunk Formation in the Lehighton and Palmerton quadrangles consists predominantly of quartzose sandstone (quartzite), quartz-, chert-, shale-, and quartzite-pebble conglomerate, siltstone, and shale, as well as a few sandstone and siltstone beds containing nodules of collophane, siderite, and chlorite. Some beds are red. Fossils are rare. The measured thickness of the Shawangunk is 1,632 feet at Lehigh Gap, and its thickness varies little in the two quadrangles. Four samples from the formation have been analyzed chemically and spectrographically (Table 2). The Shawangunk Formation underlies a prominent ridge, Blue Mountain, and the best exposures are found in wind and water gaps (see sections 3 and 4, Epstein and Epstein, 1972, p. 31-42), but outcrops are scattered on the top of the mountain and on the steep south slope.

### *Weiders Member*

The Weiders Member was named by Epstein and Epstein (1972) for beds consisting predominantly of conglomerate and quartzite exposed along the abandoned Lehigh and New England Railroad in Lehigh Gap (see section 3, Epstein and Epstein, 1972, p. 31-41). The member is named for Weiders Crossing about 1,000 feet south of the gap.

The most abundant rock types in the Weiders Member are crossbedded and planar-bedded conglomerate and quartzite (Figure 8). Large quartz pebbles distinguish the Weiders from the overlying Minsi Member. The upper contact is placed at the top of the highest bed containing pebbles more than 2 inches long, a characteristic that is readily mapped in the report area. Defining the top of the member in this way, the Weiders is 189 feet thick at the type locality in Lehigh Gap and about 50 feet at Bake Oven Knob. The thickness varies according to the presence or absence of pebbles more than 2 inches long in the topmost bed of the member. At Bake Oven Knob, the top 6 inches of the upper 39 feet is coarsely conglomeratic. If this bed were missing, the Weiders would be only 11 feet thick there. The Weiders is apparently thickest (about 220 feet based on construction of cross sections) at Little Gap.

Basal beds of the Weiders Member rest unconformably on beveled shale and graywacke of the Pen Argyl Member of the Martinsburg Formation. Fault gouge, breccia, and slickensides indicate that the interval

Table 2. *Chemical and Semiquantitative Spectrographic Analyses of Rocks from the Shawangunk Formation*

Values above the double line are from rapid-rock analyses by P. Elmore, G. Chloe, J. Kelsey, S. Botts, H. Smith, J. Glenn, and L. Artis, U.S. Geological Survey. Values, in parts per million, below double line are from semiquantitative spectrographic analyses by J. L. Harris, U.S. Geological Survey. N, not detected or at limit of detection; L, detected but below limit of determination. The following elements were looked for and not detected or were found in amounts at the limit of detection: As, Au, Bi, Cd, Eu, Ge, Hf, In, Li, Nd, Pd, Pr, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, U, W, Zn. The following elements were not looked for in samples 1-3 and were looked for but not detected in sample 4: Dy, Er, Gd, Ho, Lu, Tb, Tm.

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ | 76.6 | 92.2 | 72.3 | 67.7 |
| $Al_2O_3$ | 11.0 | 2.5 | 12.3 | 4.8 |
| $Fe_2O_3$ | .68 | 1.0 | 5.3 | 6.6 |
| FeO | 2.2 | 1.1 | 1.3 | 2.5 |
| MgO | 1.7 | .37 | 1.0 | 1.0 |
| CaO | .24 | .13 | .14 | 5.5 |
| $Na_2O$ | .03 | .00 | .00 | .02 |
| $K_2O$ | 3.2 | .26 | 3.5 | 1.3 |
| $H_2O-$ | .24 | .09 | .29 | .65 |
| $H_2O+$ | 2.3 | 1.2 | 2.5 | 2.2 |
| $TiO_2$ | .75 | .28 | 1.1 | .43 |
| $P_2O_5$ | .11 | .00 | .06 | 4.1 |
| MnO | .04 | .04 | .03 | .81 |
| $CO_2$ | <.05 | <.05 | <.05 | 1.7 |
| Total (percent) | 99.1 | 99.2 | 99.8 | 99.3 |
| Ag | N | N | N | 5 |
| B | 70 | L | 50 | L |
| Ba | 500 | 50 | 200 | 200 |
| Be | 2 | N | 1 | 2 |
| Co | 7 | N | 15 | 15 |
| Cr | 50 | 5 | 70 | 50 |
| Cu | 30 | 10 | 3 | 50 |
| La | 70 | N | 70 | 50 |
| Mo | N | N | N | 5 |
| Nb | 20 | 7 | 20 | 7 |
| Ni | 30 | L | 30 | L |
| Pb | N | N | 2 | 3 |
| Sc | N | N | N | 7 |
| Sr | 10 | 3 | 50 | 200 |
| V | 70 | 20 | 70 | 50 |
| Y | 15 | 10 | 50 | 100 |
| Zr | 200 | 100 | 700 | 500 |
| Ce | 300 | 200 | 500 | 500 |
| Ga | 7 | 2 | 10 | 10 |
| Yb | 1.5 | 1 | 5 | 10 |

## Table 2. (*Continued*)

1. Lithic graywacke, Weiders Member of the Shawangunk Formation, 5 feet above base of the Shawangunk Formation (unit 3, section 3, Epstein and Epstein, 1972, p. 31-41), abandoned Lehigh and New England Railroad grade, Lehigh Gap, Northampton County, Pa. Figure 18 is photomicrograph of sample.
2. Orthoquartzite, Lizard Creek Member of the Shawangunk Formation, 860 feet above the base of the Shawangunk Formation (unit 43, section 3, Epstein and Epstein, 1972, p. 31–41), abandoned Lehigh and New England Railroad grade, Lehigh Gap, Carbon County, Pa. Figure 29 is photomicrograph of sample.
3. Very fine grained hematitic graywacke, Lizard Creek Member of the Shawangunk Formation, 1,000 feet above the base of the Shawangunk Formation (unit 54, section 3, Epstein and Epstein, 1972, p. 31–41), abandoned Lehigh and New England Railroad grade, Lehigh Gap, Carbon County, Pa. Figure 36 is photomicrograph of sample.
4. Calcareous and chloritic sandstone and siltstone with nodules of collophane and siderite, Lizard Creek Member of the Shawangunk Formation, 1,280 feet above the base of the Shawangunk Formation (unit 69, section 3, Epstein and Epstein, 1972, p. 31–41), roadcut along Pa. Route 248, Carbon County, Pa. Figure 38A shows sample.

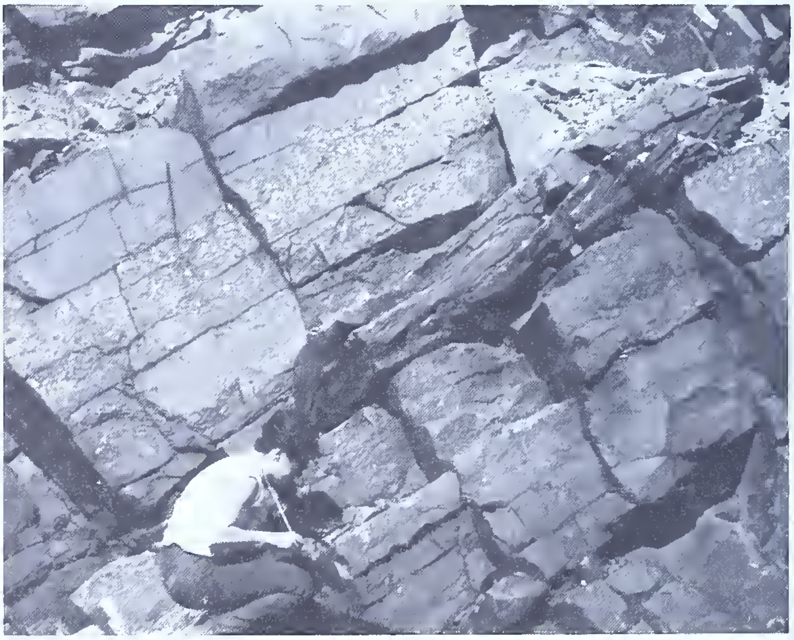


Figure 8. Interbedded planar-bedded conglomerate and crossbedded medium- to very coarse grained quartzite in the Weiders Member of the Shawangunk Formation, Lehigh Gap. Rounded to subangular white quartz and dark-gray chert pebbles and cobbles are as much as 3 inches long.

at and just below the contact is also a zone of detachment (see Epstein and Epstein, 1969, and section on structural geology in this report).

The Weiders Member is well exposed at the type section in Lehigh Gap and Little Gap, as well as along the road one-half mile southwest of Bake Oven Knob in the Slatedale quadrangle south of the Lehighton quadrangle. Good exposures are found at many places between these localities where the member forms cliffs and steep dip slopes on the south side of Blue Mountain. In the southwestern part of the Lehighton quadrangle, the Weiders, repeated by faulting, holds up narrow ridges as much as 50 feet high on top of Blue Mountain.

Most conglomerates in the Weiders are massive and planar bedded; beds are as much as 3 feet thick. The pebbles and cobbles are subrounded to rounded and consist of quartz, chert, and sandstone. At Lehigh Gap they are as much as 3 inches long; they are largest at Lehigh Furnace Gap where quartz cobbles are 6.5 inches long. At several other localities, 4-inch cobbles are common. In general, the rock breaks through the pebbles, except in the basal 2.3 feet (exposed only at Lehigh Gap) where the rock is leached of cement, weathered to moderate brown (5YR4/4) to dark-yellowish orange (10YR6/6), and the pebbles are easily removed from the matrix. Flattened mud galls as much as 8 inches long are scattered throughout the member.

The pebbles and cobbles in the Weiders give a direct clue to the possible source rocks for the Shawangunk, so they will be discussed in detail. In general, vein quartz is the most abundant pebble type, especially in the upper part of the unit where it makes up more than 70 percent of the pebbles and cobbles longer than ¾ inch (Figure 9). Near the bottom of the Weiders, siliceous sandstone pebbles are abundant and make up more than 70 percent of the pebbles in the basal bed. Chert pebbles generally do not exceed 2 inches in length and make up about 20 to 50 percent of the pebbles throughout the Weiders. Mud galls and shale chips form less than 10 percent of the larger pebbles, but argillite rock fragments less than half of an inch long may account for as much as 15 percent of some beds. Polymictic conglomerates are most common in basal beds (Figures 10 and 11).

The sandstone pebbles are similar to sandstone beds in the Weiders in that muscovite is abundant and most pebbles are protoquartzites (Figure 12). Quartz grains are generally angular to subrounded and single crystals with undulose extinction, although composite grains are abundant. Overgrowths are common, and many grains have sutured contacts. Discrete detrital chert grains were seen, and many of the sandstones are cemented with chert. Nonopaque heavy minerals in the pebbles are minor and consist of euhedral to rounded zircon and tourmaline and lath-shaped muscovite and minor biotite. Apatite is common in one sample. The presence of rounded tourmaline and zircon in pebbles in the Shawangunk indicates that the Shawangunk is a multicycle deposit.

The shale pebbles in the Weiders Member consist of two types: 1) large greenish-gray (5GY6/1) mud galls (Figure 10), which are similar

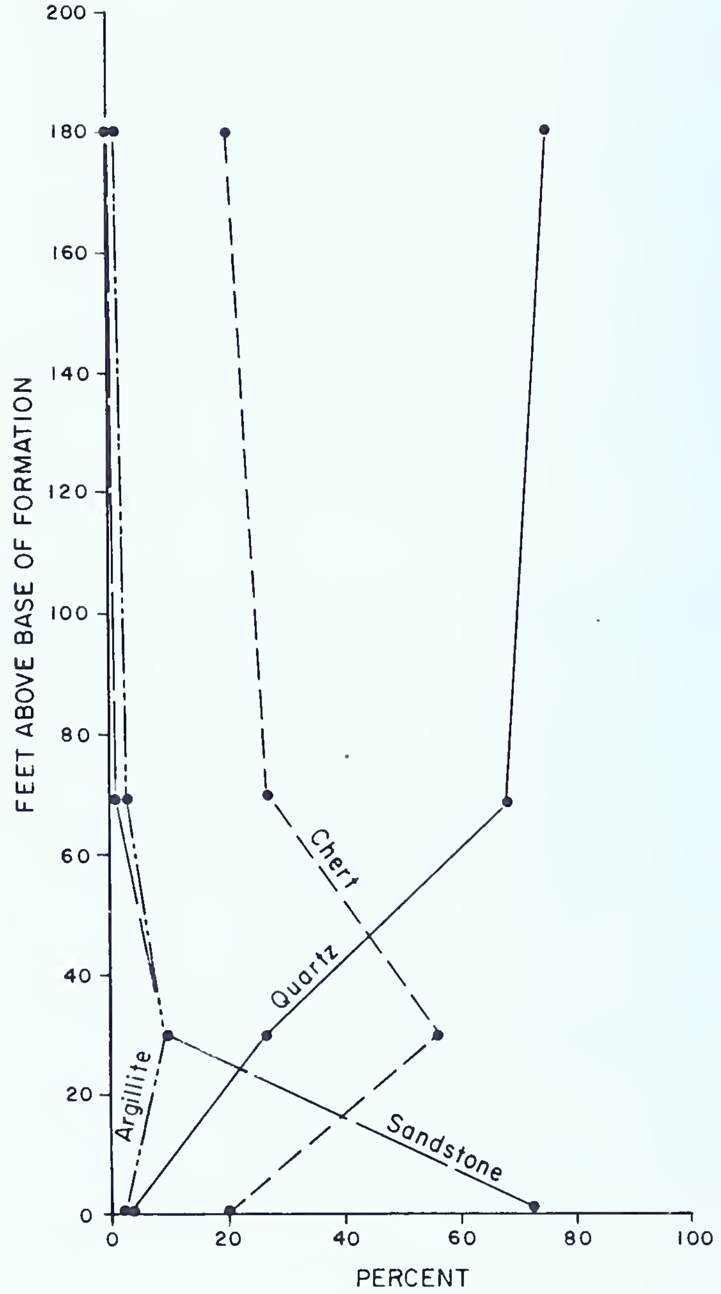


Figure 9. Percentage of pebble types (>0.75 in. long) in Weiders Member of the Shawangunk Formation at Lehigh Gap.

to interbedded shales and which appear to have been eroded from semiconsolidated mudbanks in rivers penecontemporaneously with deposition of the sands and gravels that make up the Weiders; and 2) smaller fragments, now weathered to shades of orange and light brown, which were

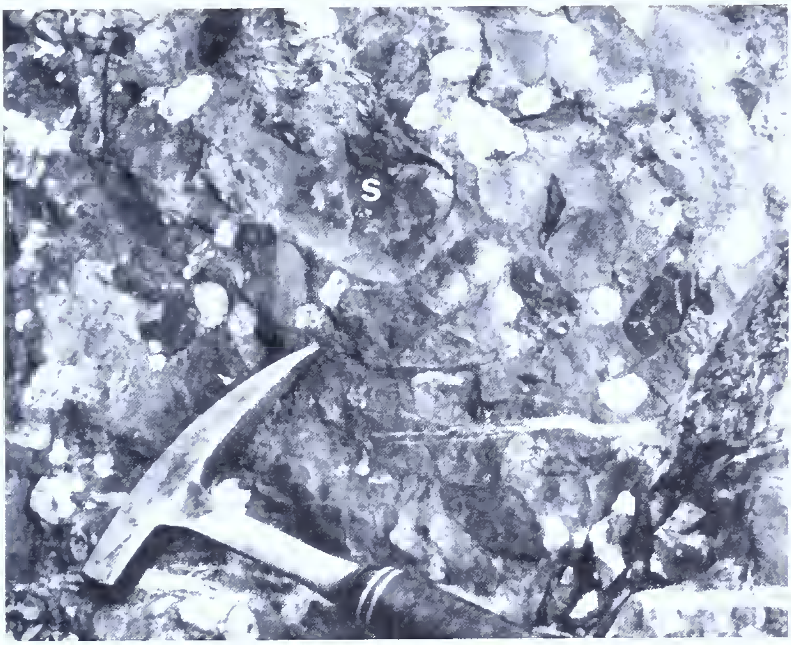


Figure 10. Polymictic conglomerate 25 feet above base of Weiders Member at Lehigh Gap, unit 5 of section 3, Epstein and Epstein, 1972, p. 31–41. Pebbles of vein quartz and quartzite (white), siltstone (gray), and chert (dark gray) are generally rounded and as much as 3 inches long. Metastable cobbles consist of shale pebbles (mud galls) nearly 8 inches long (s) that are flattened parallel to bedding. These were probably derived from slumping of mudbanks of streams (see section on environments of deposition) rather than from erosion of underlying bedrock as the shale fragments shown in Figures 11, 13, and 14.

derived from consolidated source rocks (Figure 13). The latter are of particular interest because they indicate the nature of some of the source beds and give data on whether the underlying Martinsburg Formation was metamorphosed to slate prior to deposition of the Shawangunk Formation. The sample shown in Figure 13 has minerals aligned parallel to the length of the pebble, but the alignment parallels what appears to be bedding. The muscovite does not appear to have recrystallized and does not have well-developed foliation as in underlying Martinsburg slate; mineral alignment in the pebble is similar to fissility seen in thin sections of unmetamorphosed and undeformed shales from other areas. Figure 14 shows one pebble in which bedding is clearly seen. The muscovite in that sample parallels bedding fissility.

The sand-sized matrix of the conglomerates described above is similar to the quartzites in the Weiders Member. These quartzites are medium-dark gray (N4) to medium-light gray (N6) and greenish gray (5GY6/1), generally medium to very coarse grained and conglomeratic, and occur in beds 1 inch to 6 feet thick. They are evenly to unevenly bedded; many

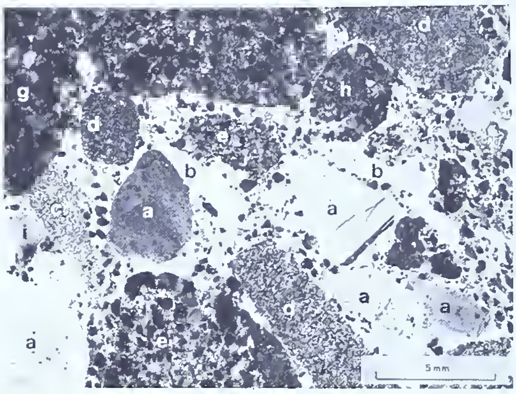


Figure 11. Negative print of thin section (crossed polarizers) of polymictic conglomerate in basal 2 feet of Weiders Member of the Shawangunk Formation at Lehigh Gap. Unit 2 of section 3, Epstein and Epstein, 1972, p. 31–41. The pebbles are angular to rounded and generally partly weathered and limonitic (post-depositional weathering) and consist of micaceous chert (a), shale (b) without mineral alignment attributable to slaty cleavage, siltstone (c), partly argillaceous very fine grained sandstone (d), medium- to very coarse grained sandstone (e), some of which contains angular quartz grains (f), or are quartzites with interlocking quartz grains (g), vein quartz (h), and a single-crystal quartz grain (i). The finer grains are mostly composite and single-crystal quartz and shale.

beds are planar. Trough and planar crossbedding are common, and in a few places ripples with wavelengths of as much as 2 feet are found. Limonite and hematite specks and sand-sized grains of grayish-orange (10YR7/4)-weathering shale fragments are scattered throughout most beds. Sorting is good to poor, and many beds, especially the conglomeratic ones, appear to be bimodal. Sieve analysis of one sample from a weathered friable sandstone lentil near the base of the Weiders shows that it is unimodal and well sorted (Figure 15). Lentils of quartzite no more than a few feet long are common in the Weiders.

The quartzites increase in maturity toward the top of the member. Lithic graywacke at the base of the member (Figures 16-18) grades up into siliceous protoquartzite (Figure 19) and rare orthoquartzite (Figure 20) with progressive decrease in finer grained matrix minerals. Durable grains of quartz, chert, and quartzite make up 47 to about 85 percent of these rocks, except in rare orthoquartzite where they make up more than 95 percent. Quartz generally occurs as single grains with slight to strongly undulose extinction. Composite vein quartz and quartzite are less common. Quartz containing vermicular chlorite inclusions (characteristic of vein quartz) and bubble trains was seen in all thin sections. The matrix minerals are generally silt-sized quartz and muscovite with a smaller amount of chlorite and lesser biotite. They form about 9 to 37 percent of most rocks. Feldspar was not seen.

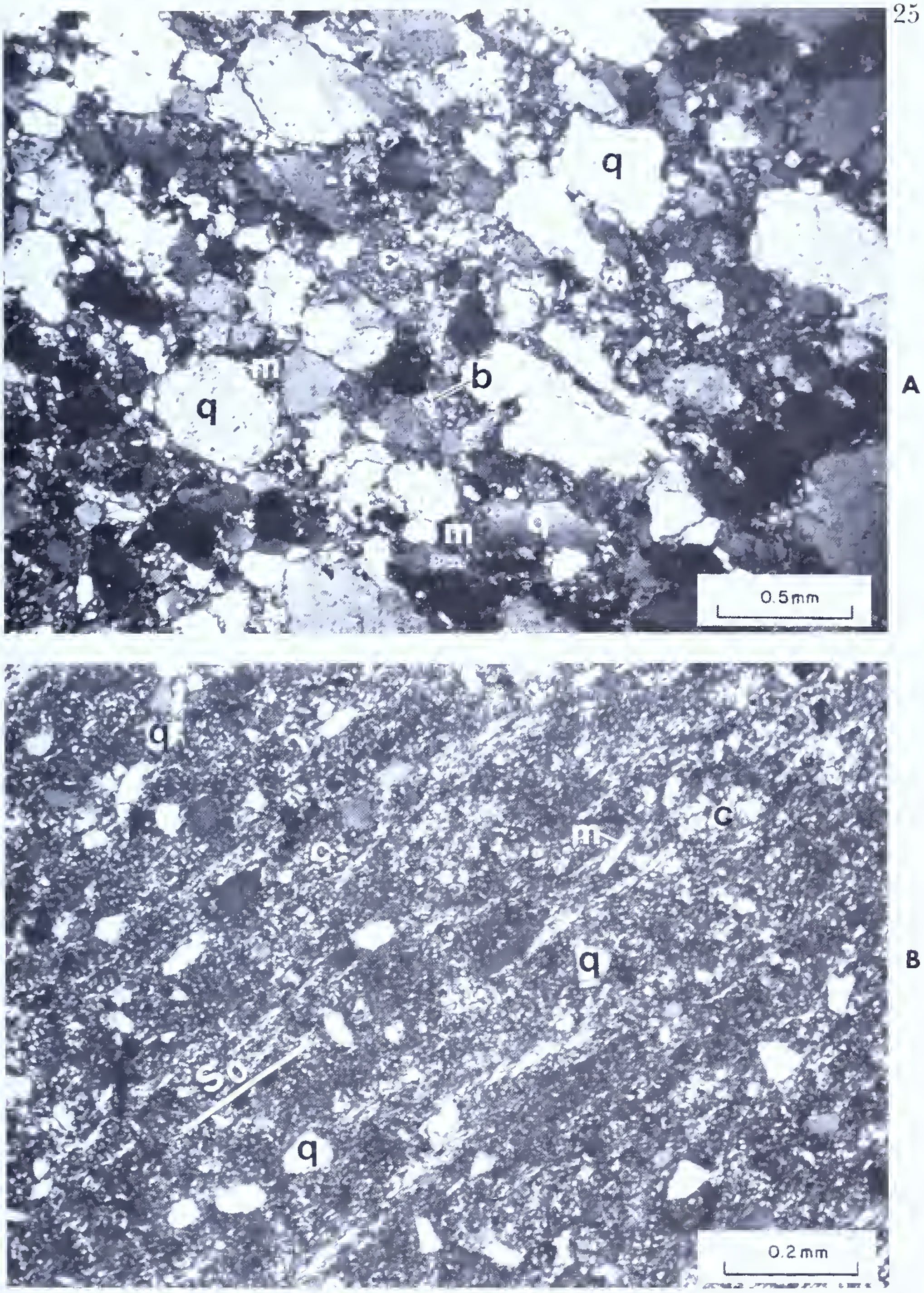
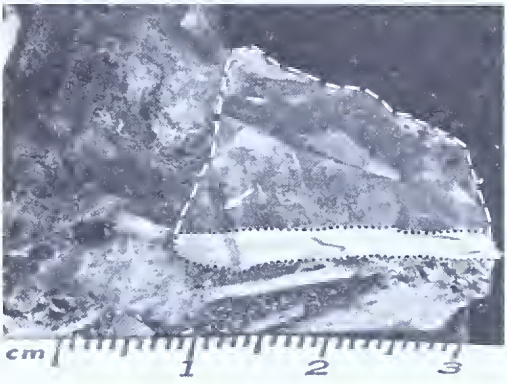


Figure 12. Photomicrographs (crossed polarizers) of pebbles in the basal 2 feet of the Weiders Member of the Shawangunk Formation, Lehigh Gap, unit 2 of section 3, Epstein and Epstein, 1972, p. 31–41. A. Poorly sorted medium- to coarse-grained protoquartzite consisting predominantly of angular to subrounded single-crystal quartz (q) with undulose extinction and lesser biotite (b) partly altered to chlorite and chert (c). The matrix (m) consists of finer quartz, muscovite, and minor biotite, and makes up about 13 percent of the sample. B. Coarse siltstone to fine-grained sandstone made up of subangular to subrounded quartz (q) and minor chert (c) and lath-shaped muscovite (m) embedded in chert cement. Fine wisps of muscovite are aligned parallel to bedding ($S_0$).



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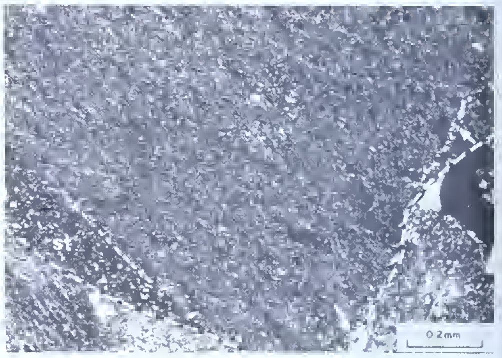

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Figure 13. Polished section of shale pebble in basal few inches of the Weiders Member, Lehigh Gap, unit 2 of section 3, Epstein and Epstein, 1972, p. 31-41. The polished section is outlined by dots; the top is outlined by dashes. In thin section, the micas are parallel to the flat sides of the pebble which appear to be bedding planes, not cleavage, but the rock is too weathered to be sure of this. (Compare with Figure 14.) The pebble contains a quartz vein (arrow) showing that it was indurated prior to deposition in the Shawangunk.

Figure 14. Photomicrograph (crossed polarizers) of part of a rock fragment (outlined with dashes) showing bedding plane (dotted) separating siltstone (st) from shale and alignment of small detrital mica grains in shale parallel to bedding. Quartz vein in pebble (arrows) that does not extend into surrounding rock shows that the pebble was indurated prior to deposition.

The rock fragments are mostly shale and lesser siltstone. Mineral orientation is generally poor (Figure 16), and only a few grains have a foliation that could be a secondary cleavage imposed in the source rocks prior to deposition.

Heavy minerals in the quartzites are chiefly muscovite and rounded to euhedral zircon and tourmaline. Biotite is relatively sparse, and only one grain of hornblende was seen (Figure 17). Slightly pleochroic light-green spherulitic chlorite fills pore spaces in several samples.

Interbedded with the quartzite and conglomerate are beds of greenish-gray (5GY6/1) argillite (indurated siltstone and claystone). They are lenticular and generally between 0.5 and 7 inches thick, although a 2-foot-thick bed is present at Lehigh Gap. These argillites are not abundant and make up less than 3 percent of the Weiders. They are similar to the greenish-gray mud clasts in the coarser beds. X-ray diffraction analyses show that the approximate average composition in the shale pebbles and bed is quartz (30 percent), muscovite (55 percent), and chlorite (15 percent). The chlorite content is generally lower than in most samples of slate from the Martinsburg Formation.

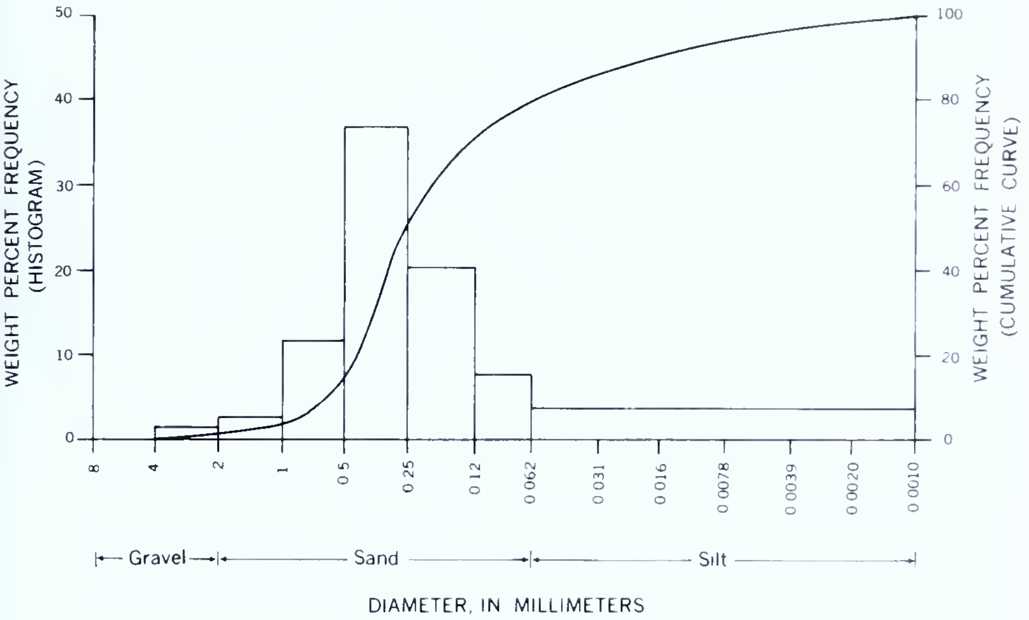


Figure 15. Histogram and cumulative curve for 4-inch-thick weathered friable sandstone lens in basal 2 feet of Weiders Member at Lehigh Gap, unit 2, section 3, Epstein and Epstein, 1972, p. 31–41. Silt and clay are averaged through six classes. The sample contains 78.3 percent sand, 20.3 percent silt and clay, and 1.4 percent granules. Sorting is good ($S_0 = 2.02$; square root of first and third quartiles), arithmetic mean of the diameter distribution is 0.35 mm, arithmetic standard deviation is 0.6. The rock is a lithic graywacke (see Figure 17).

### *Minsi Member*

Epstein and Epstein (1972) named the Minsi Member for quartzite and conglomeratic quartzite near Mt. Minsi, Monroe County, Pennsylvania. The type section is along U.S. Interstate 80 in Delaware Water Gap, Warren County, New Jersey, where the member is about 300 feet thick.

In the Lehighton and Palmerton quadrangles, the Minsi Member is similar to the rocks in the type section and consists of very light gray (N8) to medium-dark-gray (N4) and light-olive-gray (5Y6/1) to greenish-gray (5GY6/1), limonitic, fine- to very coarse grained, but generally medium-grained, planar-bedded and crossbedded conglomeratic quartzite (Figure 21). Bedding is generally uneven and rippled in places. *Arthrophycus* is rare. Pebbles consist of subangular to rounded quartz and lesser chert. These are less than 2 inches and generally between ½ and 1 inch in diameter. Beds are 1 inch to 2.5 feet thick.

Medium-dark-gray (N4) and light-greenish-gray (5GY8/1) to greenish-gray (5GY6/1) argillite (mainly silty shale) beds, 0.5 to 3 inches thick, are scattered in the Minsi. Flattened mud clasts of similar lithology, as

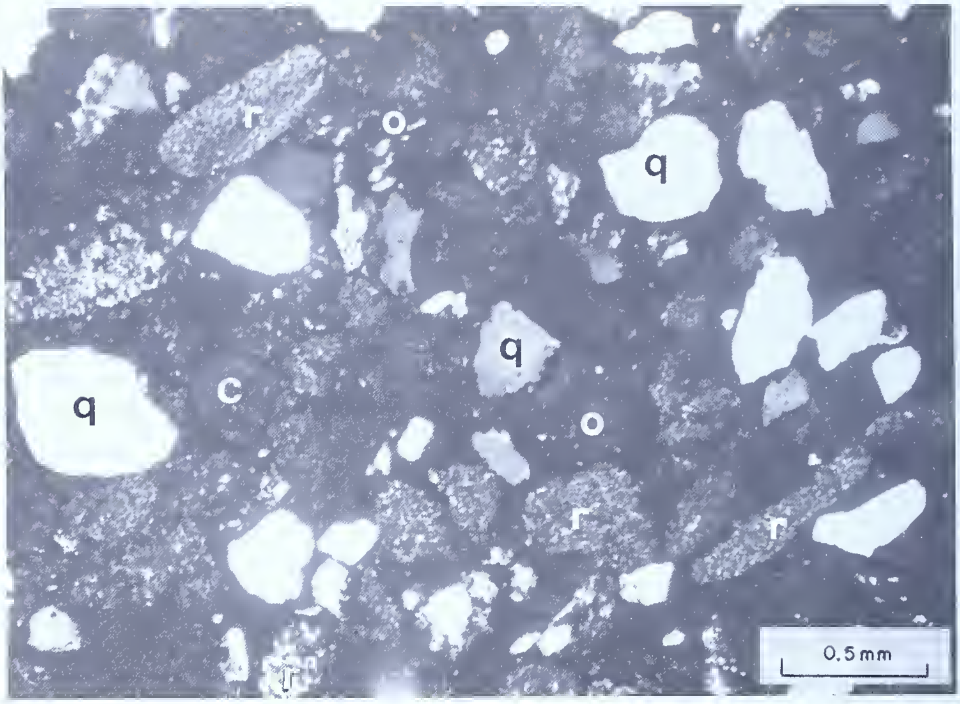
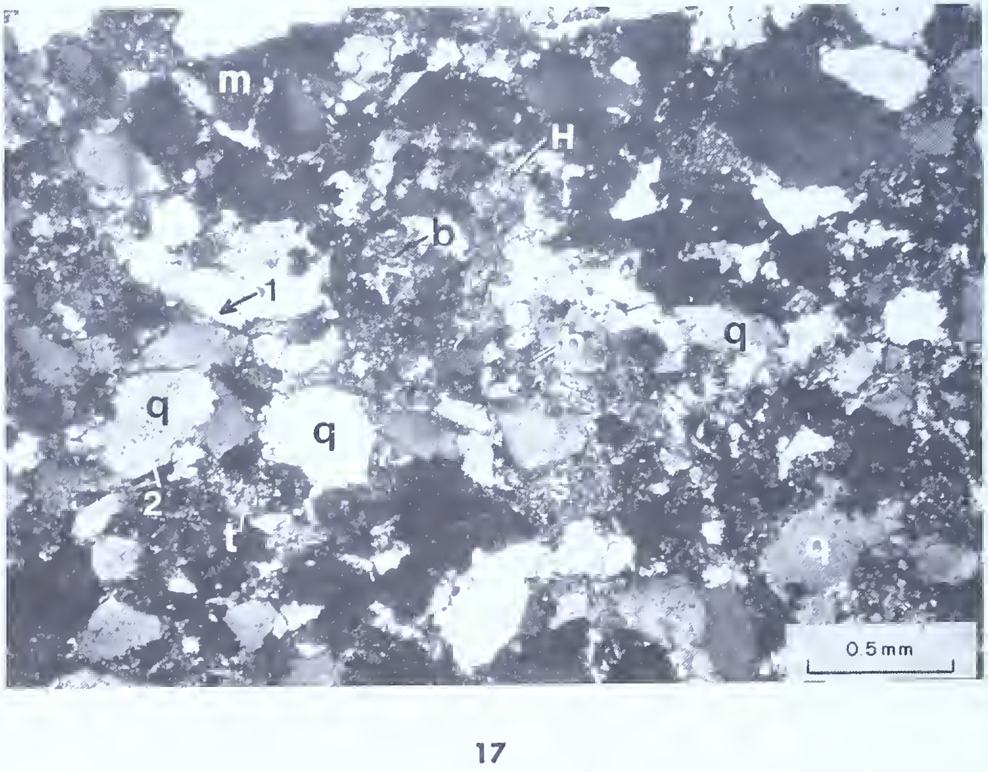
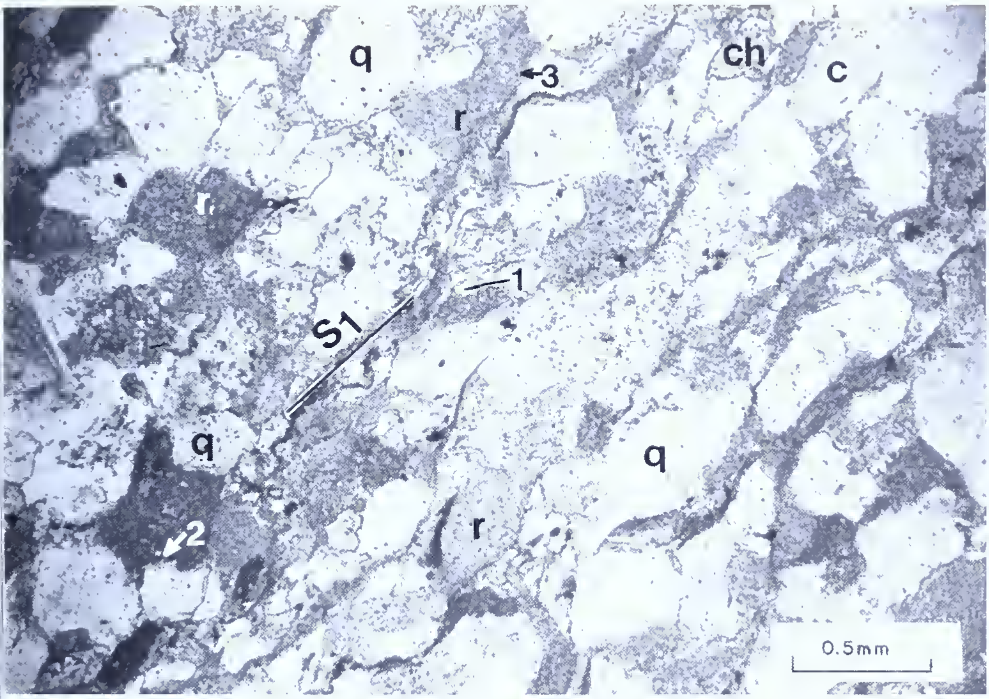


Figure 16. Photomicrograph (crossed polarizers) of medium-grained lithic graywacke from base of Weiders Member at Lehigh Gap, unit 2 of section 3, Epstein and Epstein, 1972, p. 31–41. Quartz grains (q, 25 percent) are angular to subrounded, generally single crystal, with undulose extinction and some with vermicular chlorite. Rock fragments (r, 30 percent) are rounded to subangular shale and minor siltstone. Mineral orientation is poor to fair, and where present is ascribed to fissility, not to secondary foliation. Chert (c, 2 percent) is generally subangular. These grains float in a matrix (37 percent) of clay-sized limonite and silt-sized quartz and muscovite. Opal (o) forms a pore filling in 6 percent of the sample.





igure 18. Photomicrograph (plane-polarized light) of medium- to coarse-grained lithic graywacke from about 5 feet above base of the Weiders Member of the Shawangunk Formation, Lehigh Gap, unit 3 of section 3, Epstein and Epstein, 1972, p. 31–41. Sample 1 in Table 2 is a chemical analysis of this rock. Quartz (q, 47 percent) is subangular to subrounded, has straight to slightly undulose extinction, is mainly single-crystal grains, and some grains have vermicular chlorite inclusions. Very fine to medium-grained micaceous quartzite (2 percent) and chlorite (c, 5 percent) make up the remainder of the durable sand fraction. Shale (r) and fewer siltstone rock fragments and rare sand-sized muscovite and biotite grains constitute about 18 percent of the rock. The matrix (about 28 percent) consists of muscovite, quartz, and subordinate chlorite and biotite. Uncommon light-green slightly pleochroic spherulitic chlorite (ch) fills some pore space. Cleavage ($S_1$) is fairly well developed, and cleavage folia (see section on structural geology) cut a few of the shale rock fragments (at 1, for example). Quartz grains have hackly terminations, and quartz and muscovite have grown in pressure-shadow areas (at 2). Many shale fragments have contributed mineral grains to the cleavage folia and consequently have diffuse outlines (3).

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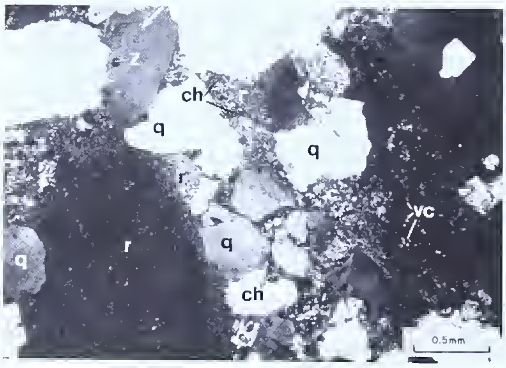
igure 17. Photomicrograph (crossed polarizers) of limonitic medium-grained lithic graywacke from weathered sandstone lens in basal bed of Weiders Member, Lehigh Gap, unit 2 of section 3, Epstein and Epstein, 1972, p. 31–41. Quartz (q, 68 percent) is angular to subrounded, has straight to strongly undulose extinction, and has interlocking contacts (at 1) or silica overgrowths (at 2). Rounded to subangular chert and cherty shale (s) make up 2 percent of the rock. Biotite (b, 2 percent) is common. Rounded to subangular shale and siltstone fragments, not seen in this field, make up 1 percent of the rock. Matrix minerals (m, 27 percent) are composed of silt-sized quartz, muscovite, biotite, and possibly chlorite. Light- to medium-green subrounded tourmaline (t) is scattered throughout. The only grain of hornblende (H) seen in all rocks examined at Lehigh Gap is present in this thin section. The rock is moderately sorted (see Figure 15).



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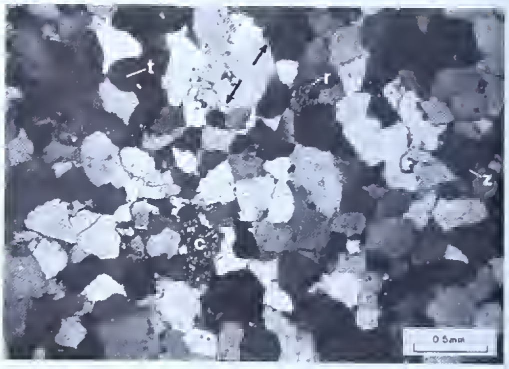

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Figure 19. Photomicrograph (crossed polarizers) of protoquartzite in Weiders Member, unit 9 of section 3, Epstein and Epstein, 1972, p. 31–41, approximately 68 feet above base of member, Lehigh Gap. The rock consists of quartz (q, about 75 percent), quartzite and chert (c, about 10 percent), and rock fragments of shale and cherty shale (r, about 3 percent), in a fine-grained matrix of muscovite, quartz, and chlorite (about 12 percent). Light-green spherulitic chlorite (ch) occurs as a pore filling. Quartz grains have rare silica overgrowths (arrow) and occasional vermicular chlorite inclusions (vc), and one grain contains a small zircon (z). Note penetrating contacts between quartz grains and large cherty shale rock fragments in lower left.

Figure 20. Photomicrograph (crossed polarizers) of well-sorted medium-grained orthoquartzite composed of 97 percent quartz, generally with interlocking contacts, but with a few overgrowths (arrows). A thin film of muscovite and chlorite rims the grains. Rare shale fragments (r), chert, and generally rounded zircon (z) and tourmaline (t) make up the remainder of the rock. Rock from approximately 110 feet above the base of the Weiders Member, Lehigh Gap, unit 10 of section 3, Epstein and Epstein, 1972, p. 31–41.

much as 7 inches long, are common in the quartzites (Figure 22). The argillite makes up less than 2 percent of the total rock in the member.

The Minsi Member is 225 feet thick at Lehigh Gap (section 3, Epstein and Epstein, 1972, p. 31-41) and at least 140 feet thick near Bake Oven Knob (section 4, Epstein and Epstein, 1972, p. 42). It extends for many miles southwest of Bake Oven Knob, probably to and beyond Schuylkill Gap where it was mapped as the Tuscarora Sandstone by Wood and others (1969).

Most of the sandstones or quartzites of the Minsi Member are submature—protoquartzites are the most common type (Figure 23). Farther east, at Delaware Water Gap, they contain enough potash feldspar to be classed as feldspathic sandstones. A finer matrix may be more abundant in some rocks, and these grade into graywackes and siltstones (Figure 24). These rocks, however, are not as abundant as the protoquartzites.

The quartz grains are generally sutured where they are in contact but some have silica overgrowths. Single grains are most common, but many

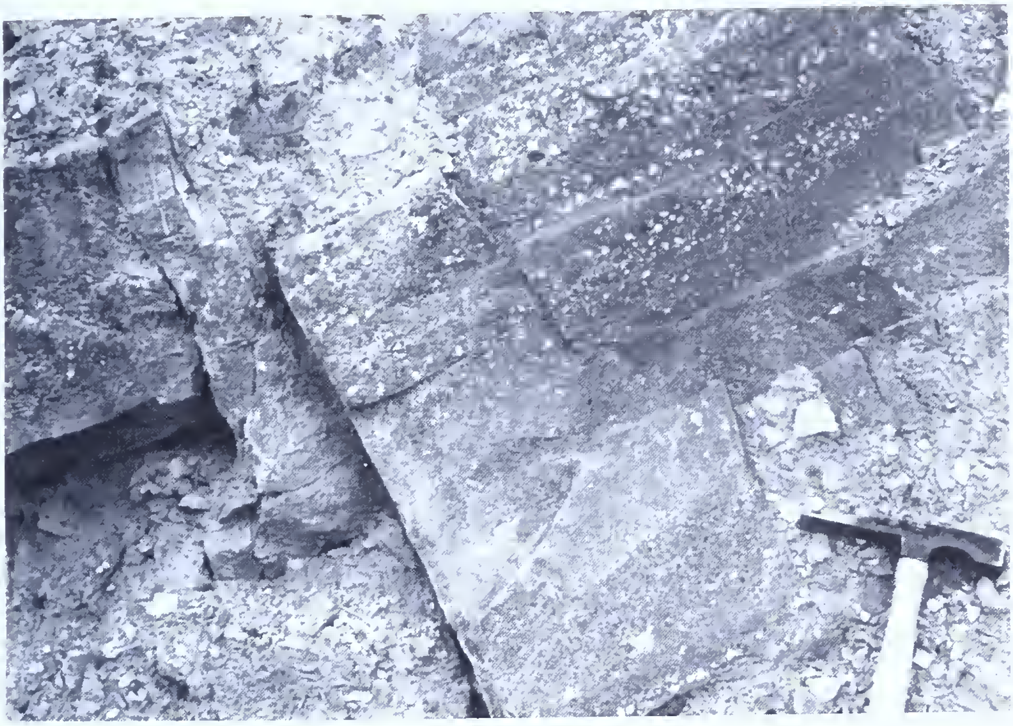


Figure 21. Crossbedded and planar-bedded quartzite and conglomeratic quartzite containing quartz and chert pebbles not more than three-fourths of an inch long in the Minsi Member of the Shawangunk Formation, Lehigh Gap. Unit 17 of section 3, Epstein and Epstein, 1972, p. 31–41.

are composite. The nonopaque heavy-mineral suite is mature and includes muscovite and well-rounded to subhedral zircon and tourmaline.

The upper contact of the Minsi Member is placed at the base of the lowest shale or siltstone in the interbedded quartzite and argillite sequence that characterizes the overlying Lizard Creek Member. This boundary is generally covered and is probably transitional through several tens of feet.

### *Lizard Creek Member*

Siltstone, shale, sandstone, and scattered red beds, conglomeratic and calcareous sandstone, and other lithic types between the Minsi Member of the Shawangunk Formation and the Bloomsburg Red Beds were included in the Clinton Formation by most previous workers in eastern Pennsylvania. This usage originated with Swartz and Swartz (1931) who defined the Clinton Group as consisting of, in ascending order, the Rose Hill Formation, the Keefer Sandstone Member at the base of the Rochester, and the Rochester Formation. The Clinton Group was traced to Swatara Gap, 30 miles southwest of Bake Oven Knob, by Swartz and Swartz (1931). Northeast of Swatara Gap, the components of the group

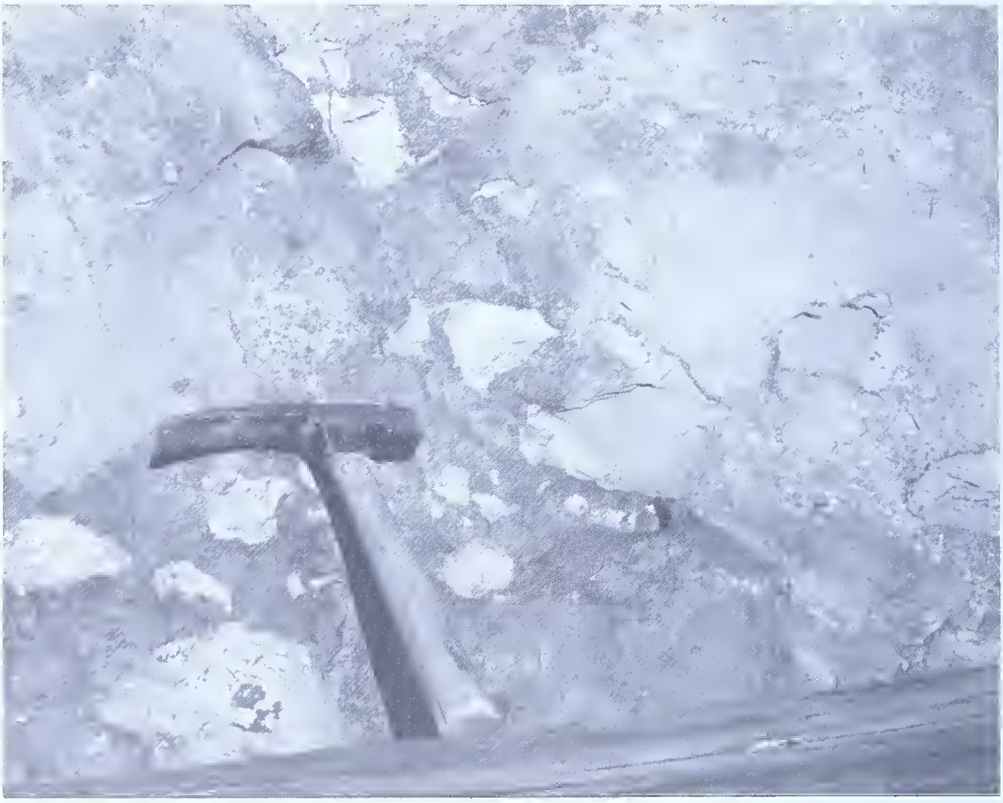


Figure 22. Shale clasts (flattened mud balls) as much as 7 inches long in quartzite float boulder in the Minsi Member at Lehigh Gap.

were not recognizable, and Swartz and Swartz designated the unit the Clinton Formation. Because the tripartite subdivision of these rocks (a prerequisite for calling them Clinton according to current practice of the Pennsylvania Geological Survey) cannot be recognized in the Lehigh Gap area, and for other reasons, Epstein and Epstein (1972) abandoned the name Clinton and named these rocks the Lizard Creek Member of the Shawangunk Formation.

The type section of the Lizard Creek Member is at Lehigh Gap in the Palmerton quadrangle (section 3, Epstein and Epstein, 1972, p. 31-41). The member was named for Lizard Creek, 3 miles west of Lehigh Gap.

At the type section, the Lizard Creek is 1,225 feet thick. Schuchert (1916) believed that the member (his "Upper Shawangunk") is 900 feet thick at Lehigh Gap, and Swartz and Swartz (1931) measured 1,093 feet for their equivalent Clinton. The Lizard Creek thins rapidly east of the Palmerton quadrangle because the upper part coarsens and is replaced by the Tammany Member of the Shawangunk Formation (Figure 7).

The Lizard Creek Member is characterized by interbedded sandstone, siltstone, and silty shale (Figure 25). It is gradational into the underlying Minsi Member but is readily separated from it by the abundant

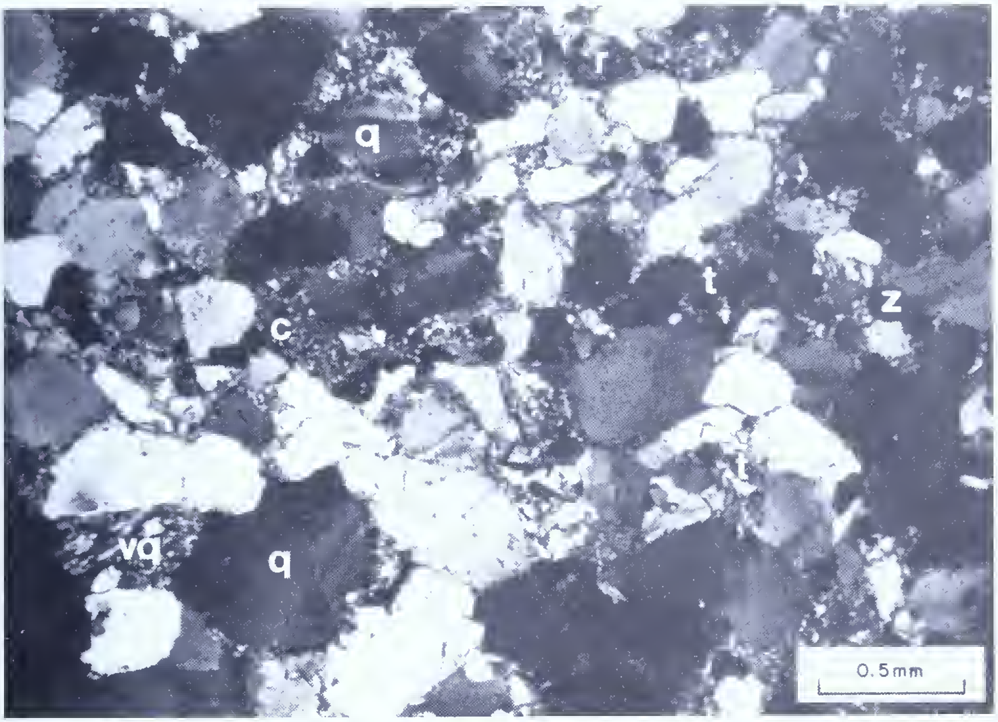


Figure 23. Photomicrograph (crossed polarizers) of moderately sorted conglomeratic medium- to coarse-grained protoquartzite in Minsi Member, about 400 feet above base of the Shawangunk Formation at Lehigh Gap, unit 21 of section 3, Epstein and Epstein, 1972, p. 31–41. Quartz (q, generally subangular single crystal, with undulose extinction, but some grains composite with strongly undulose extinction) and minor chert (c) and quartzite make up 86 percent of the rock, and along with rock fragments (r, mostly shale, less than 1 percent) and scattered rounded to subhedral zircon (z), rare tourmaline (t), leucoxene, and limonite are in a silt- to very fine sand-sized matrix of muscovite, quartz, and lesser chlorite (14 percent).

medium- to dark-gray siltstone and shale. The upper contact of the Lizard Creek is placed at the base of the lowest red bed of the dominantly red sequence of the overlying Bloomsburg Red Beds. The Bloomsburg and Lizard Creek are transitional through 162 feet of red, green, and gray sandstone, siltstone, and minor shale at Lehigh Gap.

The sandstones in the Lizard Creek are generally fine to medium grained, but range from very fine to very coarse grained. Locally, they are silty or conglomeratic, containing quartz pebbles as much as 0.5 inch long. Sorting is fair to good. Most sandstones are limonitic, a few have carbonate cement, others have chlorite pore fillings, and some contain rare specks of graphite about 2 mm in diameter. They are evenly to unevenly bedded, laminated to thick bedded (some beds are as much as 8 feet thick), and are also lenticular. Many thin lenticular beds are cross-laminated (flaser bedded, Figure 26). The sandstones are planar bedded

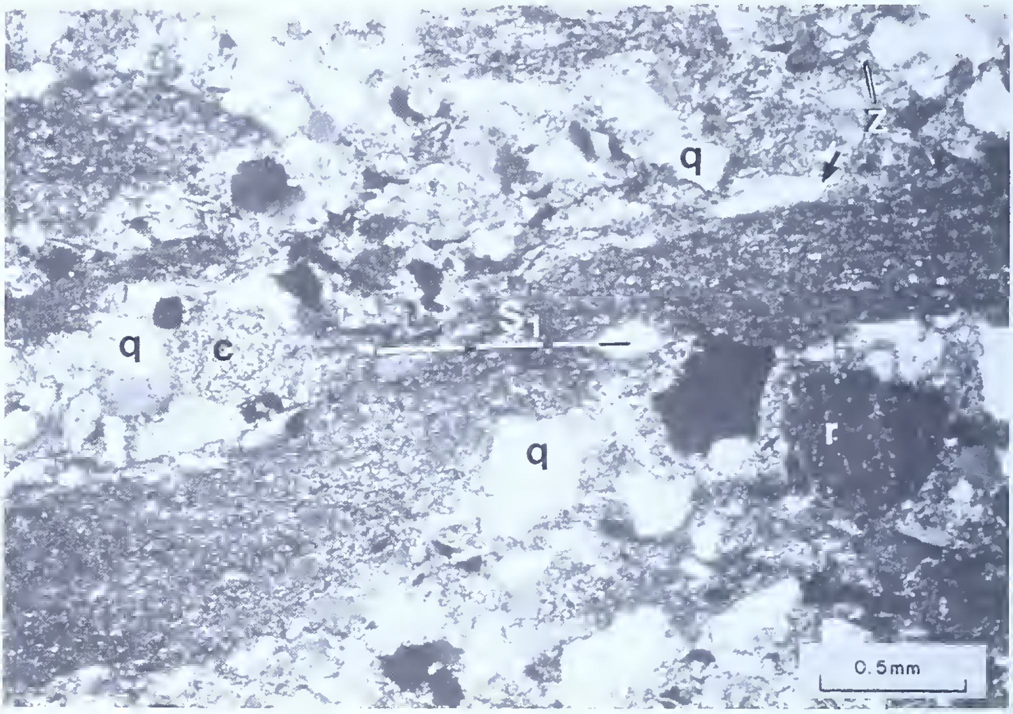


Figure 24. Photomicrograph (crossed polarizers) of unevenly laminated fine- to medium-grained silty sandstone (lithic graywacke) and siltstone, about 270 feet above base of the Shawangunk Formation in the Minsi Member at Lehigh Gap, unit 17 of section 3, Epstein and Epstein, 1972, p. 31–41. Siltstone laminae extend from upper right to lower left. Cleavage ($S_1$) is at an angle of about 20° to bedding. Quartz (q) is generally angular, single crystal, and has straight to undulose extinction. Many quartz grains are elongated parallel to cleavage (as at arrow) because of pressure solution. Chert (c) is subrounded to subangular. Rock fragments (r), mostly shale, are uncommon, as are euhedral to rounded zircon (z) and tourmaline. The silt matrix and laminae are made up mostly of quartz, muscovite, and chlorite.

to crossbedded, and many are rippled. Both trough and planar crossbeds are common. Crossbed sets range from less than 0.5 inch to more than 2 feet in thickness. The sandstones are in sharp to gradational contact with beds above and below. Many basal surfaces are filled channels of low relief (Figure 27). Colors on fresh surfaces are dark gray (N3) to very light gray (N8), light-greenish gray (5GY8/1) to dark-greenish gray (5GY4/1), and, to a lesser extent, very light bluish white (5B8/1) to bluish gray (5B6/1). They weather to shades of gray, brown, and orange. Other red sandstones are described later in this section. Thin shale intercalations and medium-dark-gray (N4) to medium-gray (N5) and greenish-gray (5GY6/1) flat shale and siltstone clasts (clay galls) as much as 4 inches long are numerous.

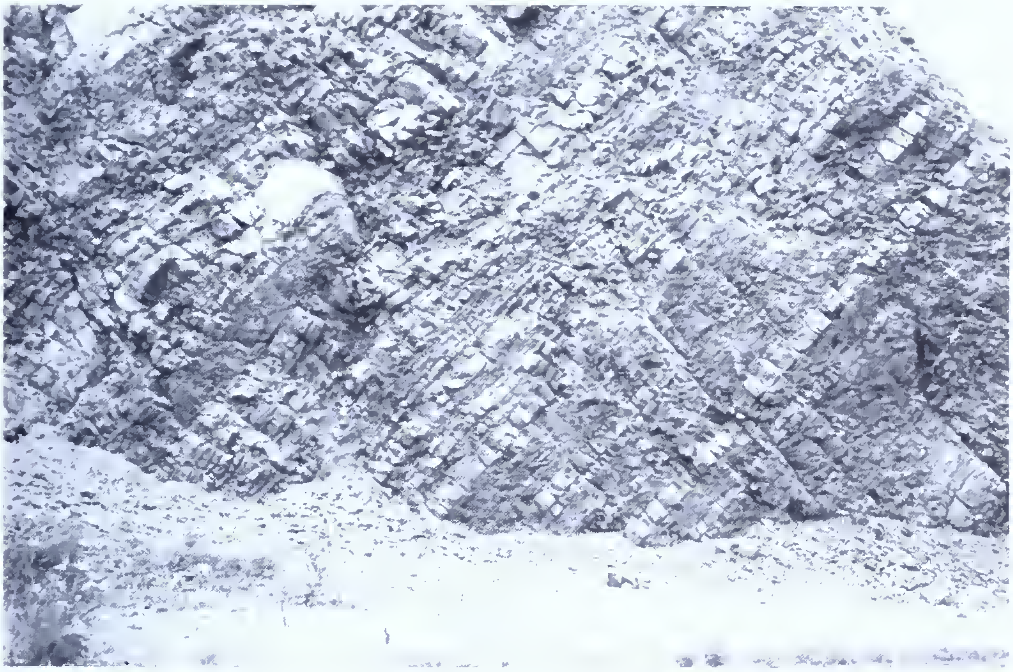


Figure 25. Evenly bedded siltstone, shale, and quartzite in the Lizard Creek Member of the Shawangunk Formation in roadcut along Pa. Route 248, Lehigh Gap, just north of Aquashicola Creek. Thickest quartzite bed is about 1.5 feet thick.

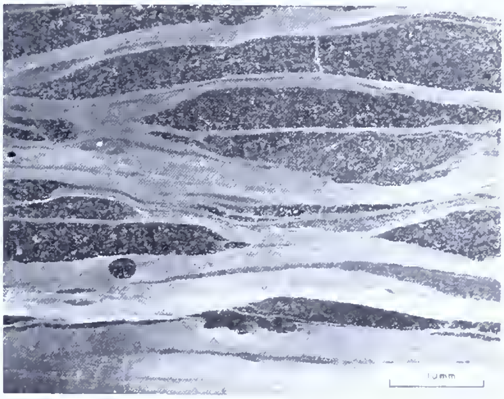


Figure 26. Ripple lensing (flaser bedding) showing oblique bedding in rippled very fine grained sandstone lenses surrounded by shale laminae, Lizard Creek Member of the Shawangunk Formation, unit 66 of section 3, Epstein and Epstein, 1972, p. 31–41. Stratigraphic top is up. Cross laminae dip to northwest (left). Note circular burrow and load casts at base of many sandstone lenses. Figure 40 is a photomicrograph of the rock. Negative print of acetate peel.

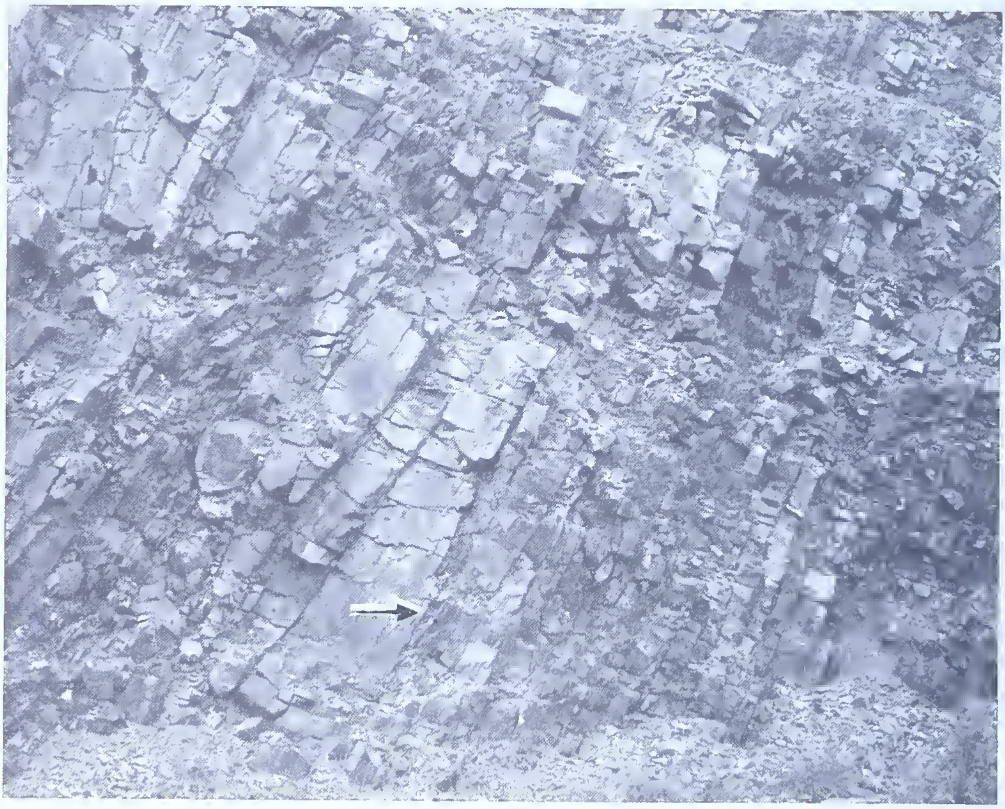
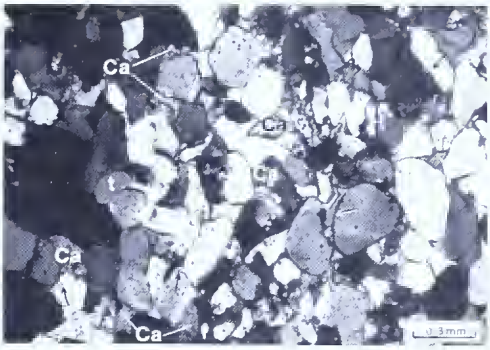


Figure 27. Low-relief channel (arrow) in medium-grained, crossbedded quartzite in the upper part of the Lizard Creek Member, unit 71 of section 3, Epstein and Epstein, 1972, p. 31–41. Bed is 3.5 feet thick at bottom. Note beveling of siltstone unit below. These beds are probably part of a tongue of the Tammany Member extending into the Lehigh Gap area (see Figure 7).

The sandstones in the Lizard Creek Member have a wide range of maturity as expressed by the percentage of matrix. They range from orthoquartzite (Figures 28 and 29) through protoquartzite (Figure 30), to subgraywacke (Figure 31) and lithic graywacke (Figure 32). Sorting is poor to excellent, and, in general, the sandstones are better sorted and grains more rounded in the orthoquartzites and protoquartzites. Quartz ranges from more than 95 percent to less than 50 percent of the sand fraction of the sandstones. Sample 2, Table 2, is the chemical analysis of a typical orthoquartzite shown in Figure 29. Most quartz occurs as single grains having undulose extinction, although most thin sections examined contain scattered composite grains that may have been derived from pre-existing quartzite. Chert is ubiquitous, rare in some sandstones, but forming as much as 5 percent of others. Where quartz grains are in contact, their borders are sutured. Quartz overgrowths are common in most samples. Besides the silica cement, limonite and hematite also



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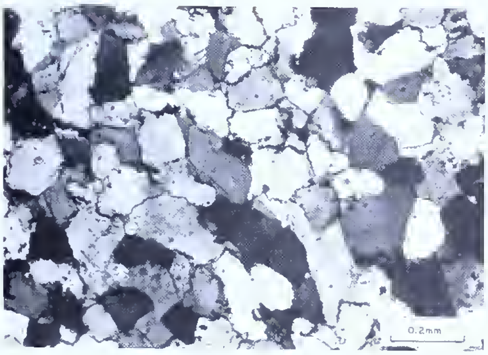

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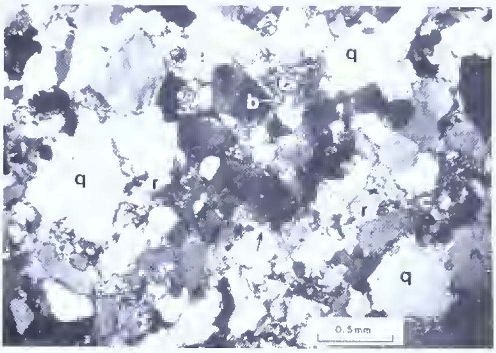

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Figure 28. Photomicrograph (crossed polarizers) of well-sorted medium-grained orthoquartzite in Lizard Creek Member of Shawangunk Formation, Lehigh Gap, unit 69 of section 3, Epstein and Epstein, 1972, p. 31–41. The rock consists predominantly of well-rounded to subrounded quartz grains, most of which have a thin rim of chlorite (dark bands) and many of which have silica overgrowths (arrows) that formed after the chlorite. Later stage sparry calcite cement (Ca) fills some pore space. Note well-rounded tourmaline (t).

Figure 29. Photomicrograph (crossed polarizers) of fine- to medium-grained well-sorted orthoquartzite in the Lizard Creek Member of the Shawangunk Formation, Lehigh Gap, unit 43 of section 3, Epstein and Epstein, 1972, p. 31–41. Quartz grains predominate, most of which have silica overgrowths. Minor chert and muscovite are also present, as well as zircon, tourmaline, leucoxene, limonite and lesser rutile. Chemical analysis of this sample shows that it is made up of more than 92 percent silica (Table 2, sample 2).

Figure 30. Photomicrograph (crossed polarizers) of granular medium-grained protoquartzite, Lizard Creek Member of the Shawangunk Formation, Lehigh Gap, unit 50 of section 3, Epstein and Epstein, 1972, p. 31–41. Quartz (q, 83 percent) is angular to subrounded with interlocking contacts, but a few grains have quartz overgrowths (arrow). Chert (c, 4 percent), shale fragments (r) and muscovite (3 percent), and rare biotite (b) and chlorite make up the rest of the framework grains. The matrix (10 percent) consists of silt-sized muscovite, quartz, and minor chlorite.

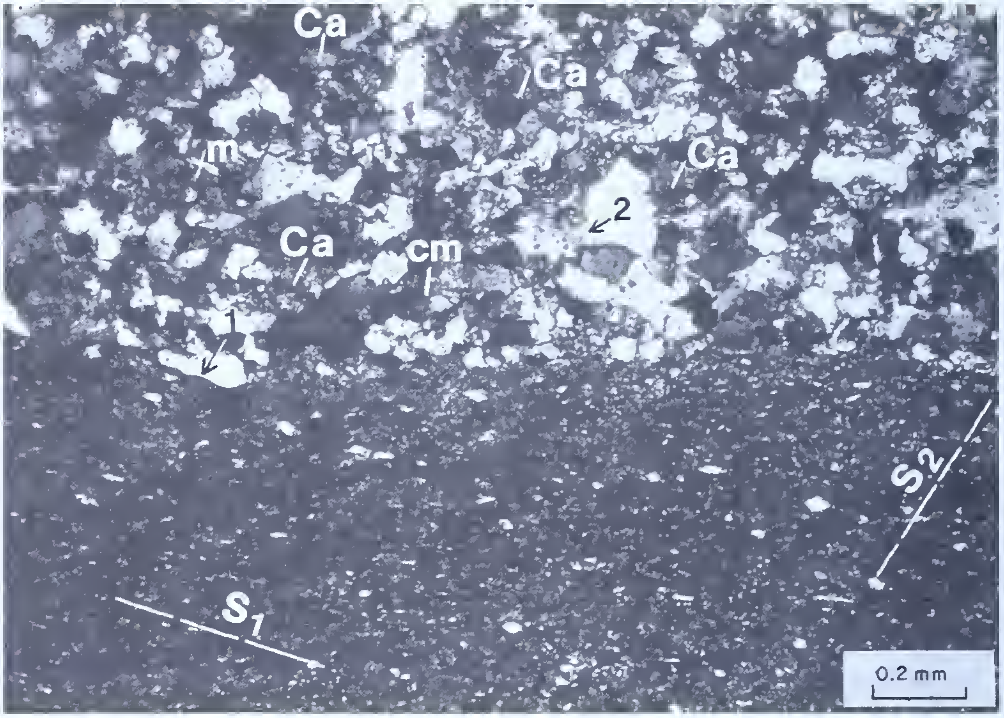


Figure 31. Photomicrograph (crossed polarizers) of finely bedded very fine grained calcareous subgraywacke and silty shale, Lizard Creek Member of the Shawangunk Formation, Lehigh Gap, unit 66 of section 3, Epstein and Epstein, 1972, p. 31–41. The sandstone is made up of subangular to subrounded quartz (73 percent) which occurs as single grains and lesser semicomposite grains, and which has undulose extinction, interlocking grain borders, and some silica overgrowths (at 2); muscovite (m, 3 percent); rounded to subrounded partly chloritized shale (2 percent); rare light-green chlorite, locally intergrown with muscovite (cm); scattered subhedral to rounded zircon, tourmaline, leucoxene, and rutile; and calcite (Ca, 11 percent) which occurs as pore filling and replacements of quartz and which may be ankeritic, judging from limonite stains. These grains are in a matrix (4 percent) of finer muscovite and quartz. The shale contains silt-sized quartz, muscovite, and minor chert, and finer muscovite, quartz, and chlorite. In general, elongate quartz and muscovite parallel bedding, but are crinkled in places by slip cleavage ($S_2$) which also cuts an earlier cleavage ($S_1$) that is not readily apparent in this orientation in the thin section. Note at 1 the partial replacement of quartz grains along bedding surface in shale that is crenulated by slip cleavage.

coat many of the grains. In several samples, pore spaces are filled with sparry calcite, which also replaces quartz (Figures 28 and 31), and light-green spherulitic chlorite (Figure 33). Sand-sized muscovite grains are common, and biotite grains, partly altered to chlorite, were seen in many samples. Rock fragments, mostly shale and siltstone, are locally absent but make up as much as 3 percent of some beds.

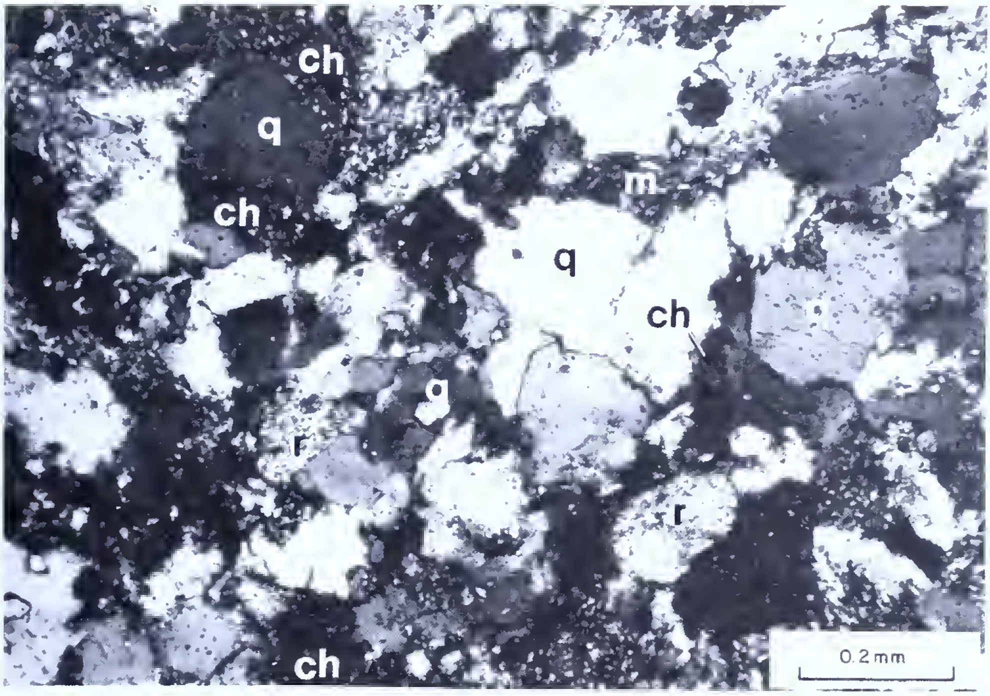


Figure 32. Photomicrograph (crossed polarizers) of fine- to medium-grained lithic graywacke, Lizard Creek Member, Shawangunk Formation, unit 53 of section 3, Epstein and Epstein, 1972, p. 31–41. The rock is fairly well sorted and consists of angular to subangular single-grain and lesser semicomposite quartz (q, 70 percent) having undulose extinction and occasional silica overgrowths; chert (4 percent); biotite, partly altered to chlorite, and spherulitic chlorite (ch) filling pore spaces (5 percent); muscovite (m, 2 percent); and rock fragments (r, chloritic shale, 1 percent), in a muscovite-quartz matrix (18 percent).

Matrix minerals in the sandstones are mostly silt- and clay-sized muscovite and quartz, with subordinate chlorite. They range in abundance from thin coatings on larger detrital grains to more than half the rock.

The nonopaque heavy-mineral suite forms as much as 2 percent of some rocks and is dominated by rounded to subrounded zircon and tourmaline (Figure 34), but some euhedral grains are present. Rutile is rare; muscovite, biotite, chlorite, leucoxene, limonite, black opaque minerals (probably magnetite), and hematite are common. The limonite and hematite are mostly alteration products of iron-bearing minerals such as chlorite and biotite.

Beds of finer clastic rocks in the Lizard Creek are shaly and sandy siltstones and silty shale composed mostly of muscovite, quartz, and chlorite (Figure 35). Silt- and sand-sized grains of mica are common on bedding planes. The siltstones and shales are medium-dark gray (N4)

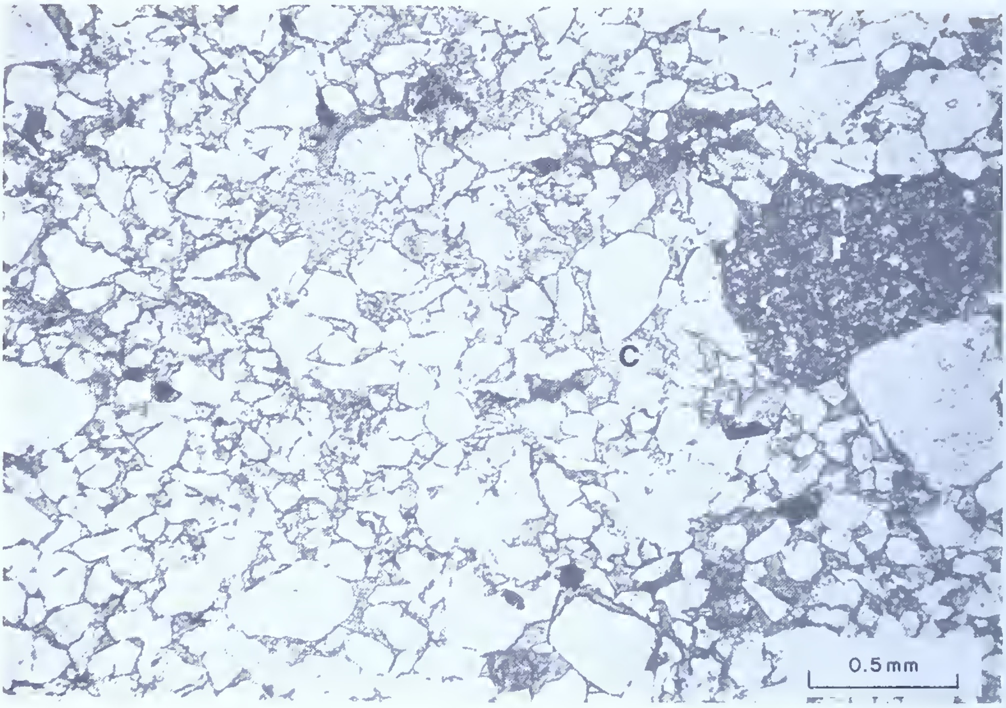


Figure 33. Photomicrograph (plane-polarized light) of protoquartzite, approaching orthoquartzite in composition, made up of subrounded to subangular quartz with green, pleochroic, spherulitic chlorite filling most pore space. Chert (c) and siltstone rock fragments (r) are not abundant. Muscovite is scattered throughout. Sample is from irregularly laminated sandstone and siltstone, unit 68 of section 3, Epstein and Epstein, 1972, p. 31–41, Lizard Creek Member of the Shawangunk Formation, Lehigh Gap.

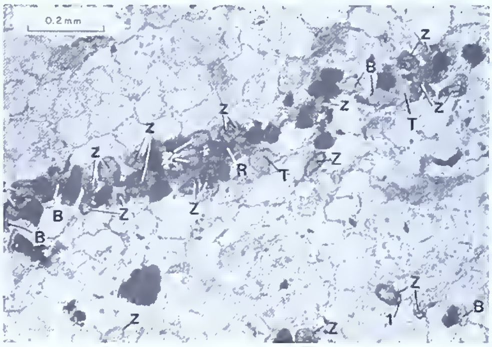


Figure 34. Photomicrograph (plane-polarized light) showing heavy minerals concentrated in lamina in laminated to slightly cross laminated fine-grained protoquartzite, Lizard Creek Member of the Shawangunk Formation, Lehigh Gap, unit 28 of section 3, Epstein and Epstein, 1972, p. 31–41. The heavy minerals are dominated by subrounded to rounded zircon (Z), one rounded grain of which has a euhedral authigenic overgrowth (at 1). Other heavies are subrounded to fractured tourmaline (T), subrounded rutile (R), angular to subrounded leucoxene (dark grains), and flakes of partly chloritized biotite (B) and muscovite (not apparent in photograph). The rock is composed of quartz and lesser chert (83 percent), shale fragments (less than 1 percent), heavy minerals (about 2 percent), and a matrix of muscovite, quartz, and chlorite (about 14 percent).

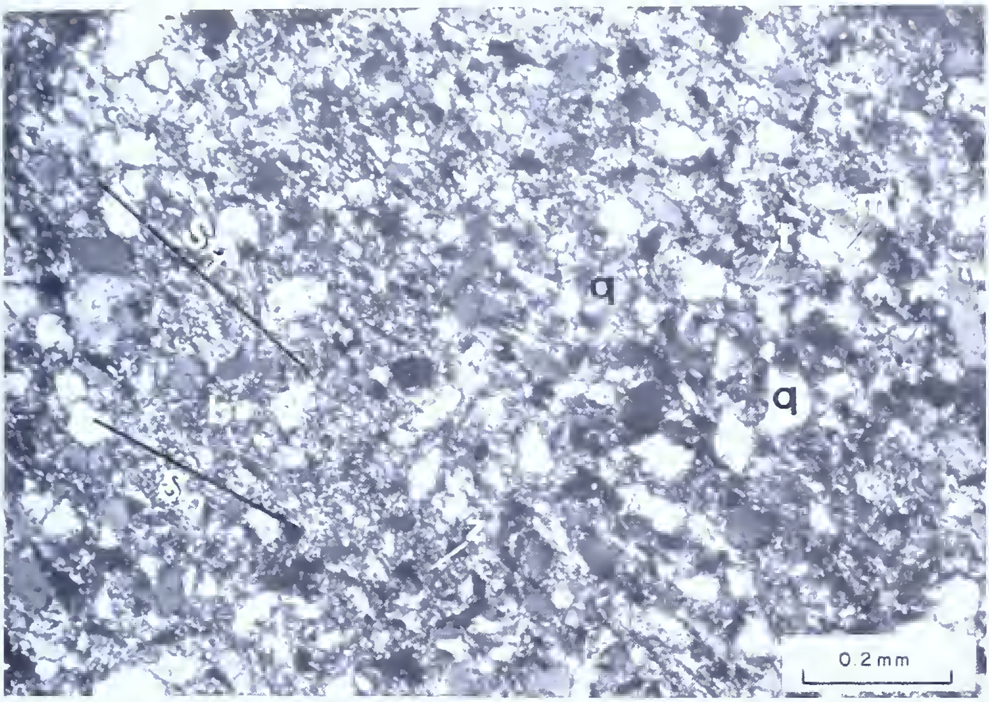


Figure 35. Photomicrograph (crossed polarizers) of laminated shaly coarse siltstone to very fine grained sandstone composed mainly of angular single-grain quartz (q) with slightly to strongly undulose extinction and muscovite (m) and less abundant chlorite with minor biotite (b), partly altered to chlorite and rounded to subhedral zircon (z) and tourmaline (t). Muscovite mostly parallels cleavage ($S_1$) which is at an angle of about 15° to bedding ($S_0$). Lizard Creek Member of the Shawangunk Formation, Lehigh Gap, unit 27 of section 3, Epstein and Epstein, 1972, p. 31–41.

to medium-light gray (N6), light-olive gray (5Y6/1) to medium-olive gray (5Y5/1), greenish gray (5GY6/1) to dark-greenish gray (5GY4/1), and light olive (10Y5/2) on fresh surfaces, as well as the colors of the red beds described later in this section. They weather to various shades of gray, green, orange, brown, and pink. Beds range in thickness from less than ¼ inch to about 6 feet. They are indistinctly bedded to laminated. Many are irregularly laminated, lenticular, cross laminated and flaser bedded, and have small-scale scour-and-fill structures. Subordinate lenses of very fine to medium-grained sandstone are common (Figure 26). Olive-gray shales are abundant above the lower 150 feet of the Lizard Creek Member at Lehigh Gap. Most of these are unevenly laminated to flaser bedded. Olive-gray shale is less abundant east of Lehigh Gap and absent at Wind Gap, 11 miles east of the Palmerton quadrangle. Bedding in many siltstones and shales was disrupted by the activity of organisms, and these rocks are burrow mottled (see Epstein and Epstein, 1972, Figure 16). Discrete burrows are generally circular, 0.25-0.5 inch in diameter, and filled with sand (Figure 26). They may be perpendicular or parallel to bedding.

As determined by semiquantitative X-ray analysis, the shales and siltstones in the Lizard Creek are made up predominantly of mica (mostly muscovite and lesser biotite, average 46 percent), quartz (average 44 percent), and chlorite (average 10 percent). Feldspar forms less than 1 percent of all samples and apparently is confined to the finer siltstones and shales, because none was identified in coarser grained rocks. Table 3 lists the rocks types and X-ray analyses.

Red-bed intervals, consisting of sandstone, siltstone, and shale and not more than 7 feet thick, are scattered throughout the Lizard Creek Member of the Shawangunk Formation (Figure 7). They do not extend very

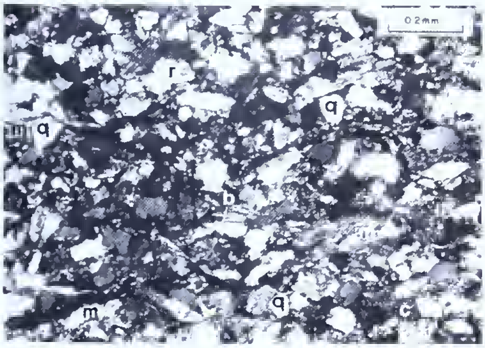
Table 3. *Semiquantitative X-ray Diffraction Analyses of Shales and Siltstones in the Lizard Creek Member of the Shawangunk Formation, Lehigh Gap*

Sample numbers are from corresponding unit in section 3, Epstein and Epstein, 1972, p. 31–41. Analytical technique is from O'Neill and others (1965) with the limits of accuracy they suggest. Most figures are probably accurate within 5 to 10 percent, although the larger figures may be off by 15 percent.

| Sample no. | Rock type | Muscovite | Quartz | Chlorite | Feldspar |
|---|---|---|---|---|---|
| | | (Percent) | | | |
| 23 | Medium-gray (N5) shaly siltstone | 48 | 51 | | <1 |
| 25 | Medium-gray (N5) silty shale | 51 | 44 | 5 | |
| 28 | Light-olive-gray (5Y6/1) shaly siltstone | 71 | 24 | 4 | 1 |
| 33 | Burrow-mottled light-olive-gray (5Y6/1) silty shale | 47 | 37 | 15 | <1 |
| 35 | Laminated light-olive-gray (5Y6/1) silty shale | 47 | 34 | 18 | <1 |
| 39 | Light-olive (10Y5/2) shale | 38 | 42 | 19 | <1 |
| 43 | Greenish-gray (5GY6/1), pale-yellowish-orange (10YR8/6)-weathering shale | 58 | 33 | 8 | <1 |
| 53 | Medium-olive-gray (5Y5/1) shale | 38 | 42 | 19 | <1 |
| 62 | Laminated light-olive-gray (5Y6/1) silty shale | 45 | 46 | 9 | <1 |
| 66 | Laminated greenish-gray (5GY6/1) shale and light-gray (N7) siltstone | 34 | 50 | 15 | <1 |
| 70 | Medium-gray (N5) silty shale | 39 | 48 | 12 | <1 |
| 71 | Medium-gray (N5) slightly silty shale | 43 | 42 | 14 | <1 |
| 73 | Light-olive-gray (5Y6/1) shale | 54 | 45 | <1 | <1 |
| 75 | Dark-greenish-gray (5GY4/1) silty shale | 36 | 59 | 4 | <1 |
| | Average percent | 46 | 44 | 10 | <1 |

far east of the Palmerton quadrangle. The red sandstones are dusky-red purple (5RP3/2) to grayish-red purple (5RP4/2), brownish gray (5YR4/1) to medium-brownish gray (5YR5/1), and moderate brown (5YR4/4), and may be color laminated or mottled with moderate-greenish gray (5GY5/1) to dark-greenish gray (5G4/1). Most are silty and very fine to fine grained, although a few are coarse grained. Most of the finer grained red sandstones are hematitic graywackes with abundant rock fragments, muscovite, and biotite (Figures 36 and 37). The hematite and finer grained muscovite and quartz matrix forms more than 30 percent of the rocks.

Some of the red sandstones are hematitic orthoquartzites and are strikingly different from the graywackes in thin section. The orthoquartzites are fine to coarse grained and generally well sorted (see Epstein and Epstein, 1972, Figure 17). Intermediate red protoquartzites are also



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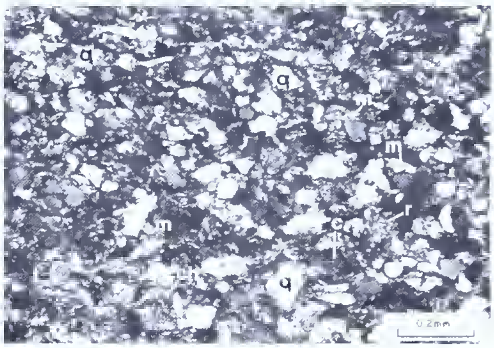

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Figure 36. Photomicrograph (crossed polarizers) of laminated silty very fine grained hematitic lithic graywacke, Lizard Creek Member of the Shawangunk Formation, Lehigh Gap, unit 54 of section 3, Epstein and Epstein, 1972, p. 31–41. The quartz (q, 57 percent) is angular to subangular and nearly all grains have a hematite coating. The framework grains also include abundant muscovite (m, 7 percent), lesser rock fragments (shale, r, 1 percent), biotite (b, 1 percent) partly altered to chlorite, chert (c, 1 percent), and minor tourmaline, zircon, leucoxene, and black opaque minerals. These are in a hematitic matrix of mostly muscovite and quartz and lesser chlorite that makes up about 33 percent of the rock. Sample 3, Table 2 is a chemical and spectrographic analysis of this rock.

Figure 37. Photomicrograph (crossed polarizers) of laminated and cross-laminated hematitic very fine grained silty sandstone, Lizard Creek Member, Lehigh Gap, unit 38 of section 3, Epstein and Epstein, 1972, p. 31–41. Quartz (q) makes up about 55 percent of the rock, and muscovite (m) is next in abundance. Other minerals are chert (c), rare chlorite (ch) that is apparently an alteration product of biotite, tourmaline (t), zircon, leucoxene, and magnetite, as well as rare shale rock fragments (r). The hematite forms a "clay" coating around many grains.

present, indicating that the sorting capabilities of the transporting media and the depositional environments were varied.

The sandstones are transitional into pale-red-purple (5RP6/2) to moderate-red-purple (5RP5/2) and pale-red (5R6/2) shaly and sandy siltstones that are color mottled and interlaminated with similar rocks that are moderate-greenish gray (5GY5/1) and light-brownish gray (5YR6/1). The mottling is due to burrowing of organisms, the remains of which have not been found (see Epstein and Epstein, 1972, Figure 16).

Semiquantitative X-ray diffraction analyses of three samples of red shale and siltstone show that, besides hematite, they average about 45 percent mica (mostly muscovite with minor biotite; range, 30-55 percent), 45 percent quartz (range, 35-60 percent), and 10 percent chlorite (range, 5-15 percent).

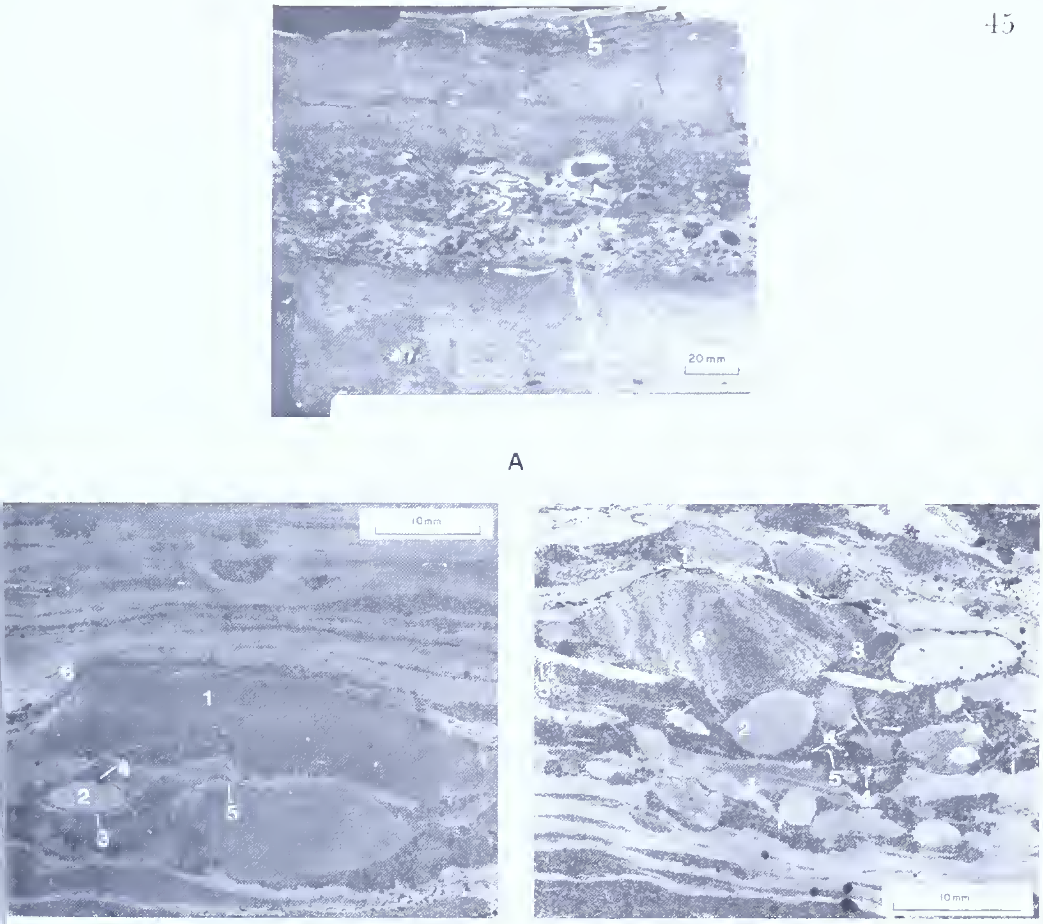
In the upper half of the Lizard Creek Member in Lehigh Gap, generally in the upper 380 feet, are more than 12 beds, 2 to 8 inches thick, of irregularly laminated sandstone to silty shale containing ovoid and irregular nodules of siderite, collophane, and chlorite, quartz pebbles, phosphatic siltstone and shale intraclasts, and fragments of linguloid brachiopods (Figures 38 and 39).

The siderite nodules are generally elliptical and 2 to 20 mm long, dark-yellowish orange (10YR6/6) to pale-yellowish orange (10YR8/6), and may be rimmed with or partly replaced by dark-yellowish-green (10GY4/4) chlorite (Figures 40A, C).

The chlorite is spherulitic, pleochroic from green to colorless, and has anomalous blue interference colors. Besides siderite, it also replaces phosphatic brachiopod shells (Figure 39) and siltstone (Figure 40D). It also occurs as intergranular fillings and reworked grains (Figure 41). The chlorite has a strong 14A reflection on X-ray diffractograms and is, therefore, not chamosite. Chamosite, however, has been found in concentrically banded oolites in ironstones of the Clinton Group of New York, Ohio, and West Virginia (Alling, 1947; Hunter, 1960, 1970; and Schoen, 1964). Some of the chlorite in the Lizard Creek may have originally been chamosite but could have been altered during low-grade metamorphism to chlorite (James, 1966). The chlorite is iron rich, judging from the high 7A/14A peak-height ratios (as much as 5:1 in some samples).

X-ray diffraction analysis shows that the collophane is carbonate fluorapatite. It is grayish black (N2) to dark gray (N3) and may weather dull white, especially the linguloid fragments. The collophane replaces siltstone intraclasts (Figures 38B, C; 40B-D), many of which are as much as 3.5 inches long. Some of it seems to be reworked grains (Figure 41).

The nodule beds, as well as others in the Lizard Creek, are rich in iron (some samples contain nearly 10 percent total iron; see chemical analysis

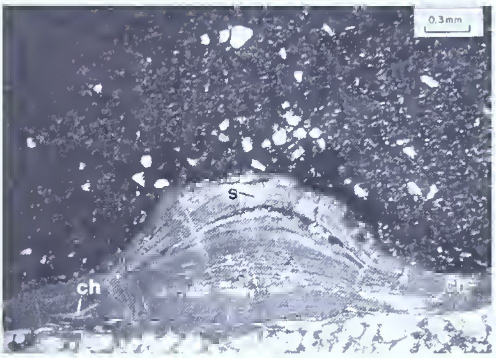


A

B

C

Figure 38. Nodule beds in the Lizard Creek Member of the Shawangunk Formation, section 3, Epstein and Epstein, 1972, p. 31–41, Lehigh Gap, Pennsylvania. A. Nodules and oolites of carbonate fluorapatite (1), rimming iron-rich shale pebbles (2), quartz pebbles as much as 8 mm long (3), and shale pebbles (4) that were probably ripped up from substrate similar to the shale at 5. This nodule bed lies between laminated well-sorted medium-grained quartzite in unit 69 of section 3, Epstein and Epstein, 1972, p. 31–41. The shale and phosphate nodules may have been deposited in the reducing environment of a lagoon and washed onto a sandbar during a storm. Chemical analysis of the shale (5) shows it to contain 8.2 percent iron expressed as $Fe_2O_3$, and 0.19 percent $P_2O_5$. Sample 4, Table 2, is a chemical and semiquantitative spectrographic analysis of this rock. Photograph of polished section. B. Nodules of siltstone partly replaced by collophane (1), siderite (2) rimmed with chlorite (3) and penetrated by quartz grain (4) (showing that the nodule was soft at time of deposition), and fragments of linguloid brachiopods (5). Note lapping of irregularly laminated shale and very fine grained sandstone on large siltstone clast (6). Serial sections of the siltstone clasts show that they are extremely irregular in shape, suggesting deposition while the siltstone was wet and plastic. Negative print of acetate peel, from unit 66, section 3, Epstein and Epstein, 1972, p. 31–41. C. Negative print of acetate peel (stained with alizarin red S and potassium ferricyanide) of nodule bed 41 inches below top of unit 69, showing nodules of siderite rimmed with chlorite (1), some of which are very irregular in shape; phosphatic siltstone (2); collophane nodules (3); fragments of *Lingula* (4); and large quartz grains (5), some of which penetrate nodules. Folded phosphatic siltstone (6) rimmed with chlorite except at top (not apparent in this peel) shows that the sediment was soft during replacement by collophane and chlorite and deformed prior to or during deposition.



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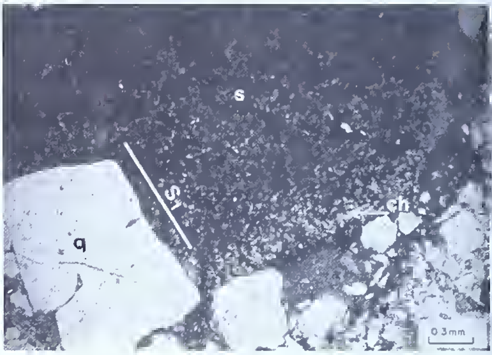

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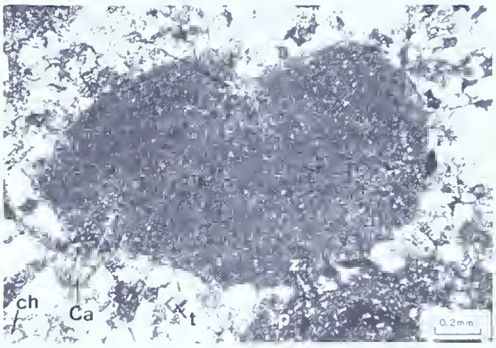
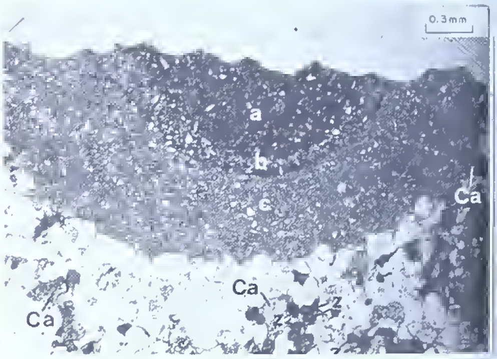
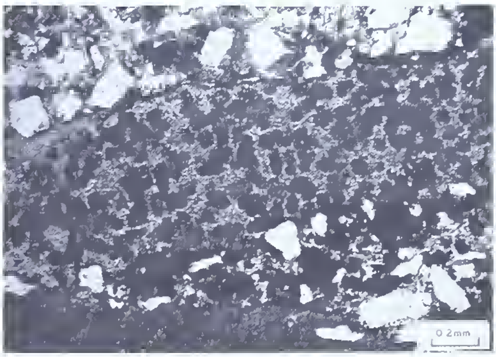


40B



40C



40D

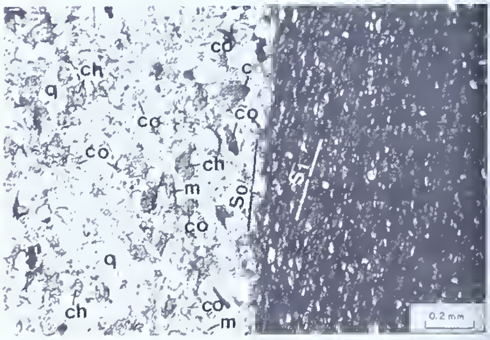


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Figure 39. Photomicrograph (plane-polarized light) showing longitudinal section through the pedicle valve of a phosphatic brachiopod, probably *Lingula*. Collophane (lighter layers) alternates with darker chitinous layers. Note fine tubuli perpendicular to the layers. The shell is partly replaced by chlorite (ch) and siderite (s). About 1 mm above this valve, out of the field of the photograph, is the brachial valve. In between the two is granoblastic siderite with scattered angular to subrounded quartz sand (light grains). Evidently sand was washed into the shell, and the dead organisms provided a reducing microenvironment favorable for deposition of siderite. Lizard Creek Member, unit 66 of section 3, Epstein and Epstein, 1972, p. 31–41.

Figure 40. Photomicrographs (A-C, plane-polarized light; D, crossed polarizers) of sideritic, phosphatic, and chloritic nodules in unit 66, section 3, Epstein and Epstein, 1972, p. 31–41, Lizard Creek Member of the Shawangunk Formation, Lehigh Gap. A. Part of a siderite nodule (s) at least 4 mm long; chlorite (ch) has replaced thin outer rim. The nodule is made up of granoblastic siderite (grains about 0.03 mm in diameter) and minor quartz and muscovite (light grains). The nodule is penetrated by a quartz granule (q) suggesting that it was soft at the time of deposition. Poorly developed cleavage ($S_1$) appears as dark wavy bands about 0.01 mm apart and along which muscovite is preferentially oriented. B. Siltstone granule replaced by collophane (dark) forming radiating rosettes. Small light minerals in siltstone are muscovite and quartz. Note sparry calcite (Ca), chlorite grain (ch), phosphatic shell(?) fragment (p), and subrounded to angular zircon (z) and tourmaline (t). C. Part of concentrically banded siderite nodule (a) rimmed with chlorite (b) and phosphatized siltstone (c). The relationships suggest penecontemporaneous growth of siderite and replacement by chlorite and, because muscovite grains are parallel to outside band, rolling of the siderite-chlorite nodule and picking up of phosphatic mud prior to final deposition. D. Elongate siltstone granule replaced by rosettes of collophane (dark) and small grains of chlorite.

Figure 41. Photomicrograph (plane-polarized light) of well-sorted fine-grained sandstone (on left) interlaminated with silty shale in unit 66, section 3, Epstein and Epstein, 1972, p. 31–41, Lizard Creek Member of the Shawangunk Formation, Lehigh Gap. Abundant irregular grains of collophane (co) and chlorite (ch) are about the same size as the quartz (q) and muscovite (m), and therefore appear to be detrital, perhaps reworked from a nearby soft sediment. The shale has well-developed cleavage ($S_1$) that is at 20° to bedding ($S_0$). The dark cleavage folia are 0.002 mm thick and 0.01 to 0.02 mm apart.

4, Table 2, and Figure 38A). Much of the iron is contained in hematite, magnetite, goethite, lepidochrosite, iron-rich chlorite, and siderite.

There is abundant evidence that the chlorite, siderite, and collophane are diagenetic precipitates or replacements of soft sediment (see Figures 38 and 40). These include rims of chlorite on nodules and clasts that are partly removed by wear prior to final deposition of the clast, penetration of nodules by quartz grains, soft rock deformation structures in nodules and clasts, and irregular shapes of some of the nodules.

*Age*

The Shawangunk Formation of eastern Pennsylvania has been regarded as Early to Middle Silurian in age (Swartz and others, 1942). This age assignment was based primarily on the presence of eurypterids and *Arthrophycus* and on regional stratigraphic considerations. The data from central Pennsylvania to New York were reevaluated by Epstein and Epstein (1972, p. 14-16) who concluded that the evidence used to date the Shawangunk Formation in eastern Pennsylvania was based on insecure stratigraphic evidence and fossils that are strongly environmentally controlled and whose ranges are poorly known due to rare occurrences. It is conceivable that the base of the Shawangunk is Late Ordovician in age as well as Early Silurian.

## SILURIAN

### Bloomsburg Red Beds

White (1883) first used the name Bloomsburg for red beds at Bloomsburg, Pennsylvania. He (1882) called the same interval the Clinton red shale in eastern Pennsylvania, whereas Rogers (1858) used the term Surgent for these rocks. Schuchert (1916) delegated these beds to the Cayugan Series and gave a historical summary. Regional relations of the Bloomsburg were described by Swartz and Swartz (1931) and some details in easternmost Pennsylvania were given by Epstein and Epstein (1969).

The Bloomsburg consists mainly of grayish-red-purple (5RP4/2) to pale-red-purple (5RP6/2) and grayish-red (5R4/2) to dark-reddish-brown (10R3/4) siltstone, shale, and sandstone, in decreasing order of abundance.

Beds of shale and siltstone are as much as 8 feet thick and commonly contain thin beds and laminae of very fine grained sandstone. These beds generally are horizontally laminated, and to a lesser extent cross laminated although in many places bedding has been obliterated by burrowing organisms (Figure 42). Mud cracks are common (Figure 43), but may be indistinct because of well-developed cleavage, especially when viewed in cross section. Pale-green (5G7/2) to greenish-gray (5GY6/1) reduction spots are numerous. Abundant irregular dark-yellowish-orange (10YR6/6)-weathering concretions are found in the shales and siltstones (Figure 44). These are dolomite, as shown by X-ray diffraction analysis, and are ferroan dolomite as indicated by a blue stain with potassium ferricyanide. The concretions are irregular masses that have replaced the host rock; they were precipitated by rising capillary waters that also spread laterally parallel to bedding. In general, these concretions are not more than 3 inches long.

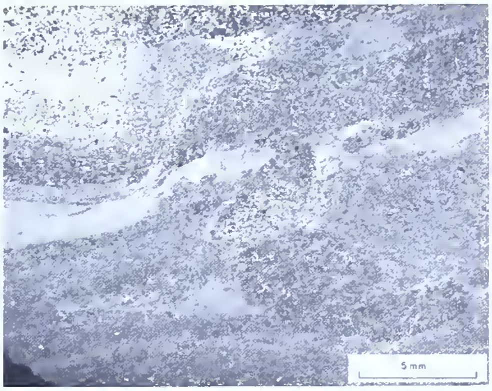


Figure 42. Negative print of thin section of burrow-mottled fine-grained sandstone, siltstone, and shale in Bloomsburg Red Beds. Discrete red sand-filled burrows interrupt green laminae in upper left and center; burrow churning disrupts laminae in lower right. Note cleavage dipping moderately to left. Unit 85 of section 3, Epstein and Epstein, 1972, p. 31–41.

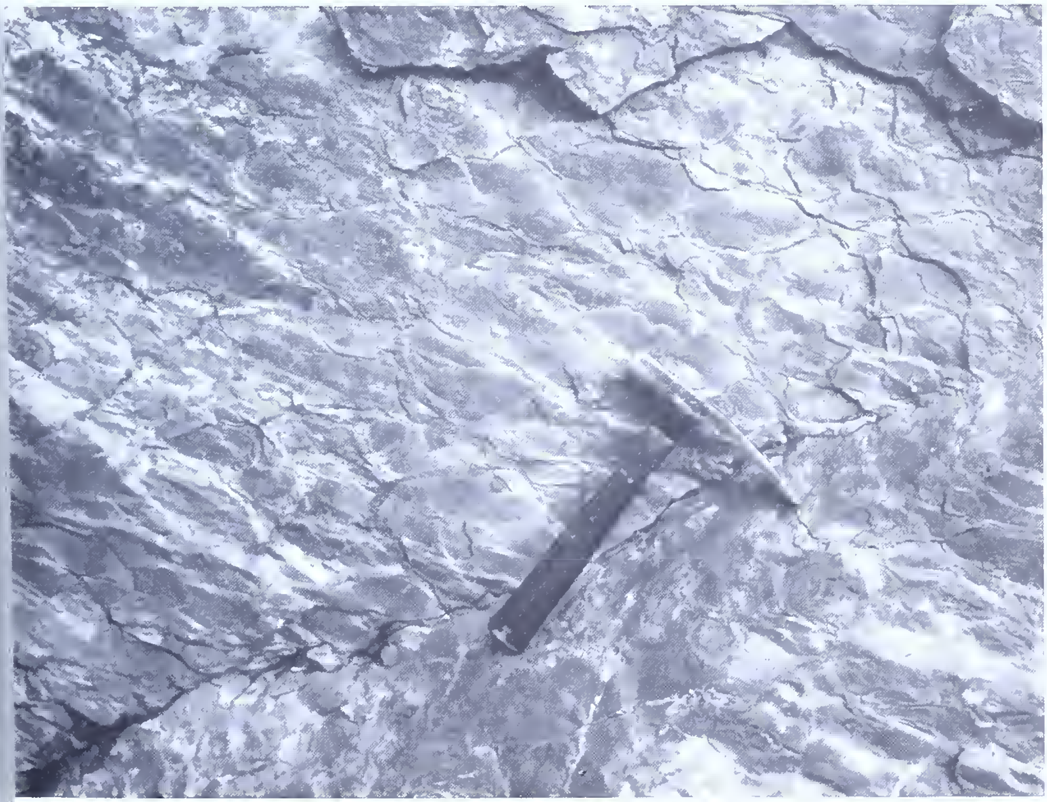


Figure 43. Mud-cracked red shaly siltstone in lower part of the Bloomsburg Red Beds, along road about 1,000 feet southwest of sewage disposal plant in Palmerton. Polygons average about 4 inches wide. The mud-crack fillings are finer shale.

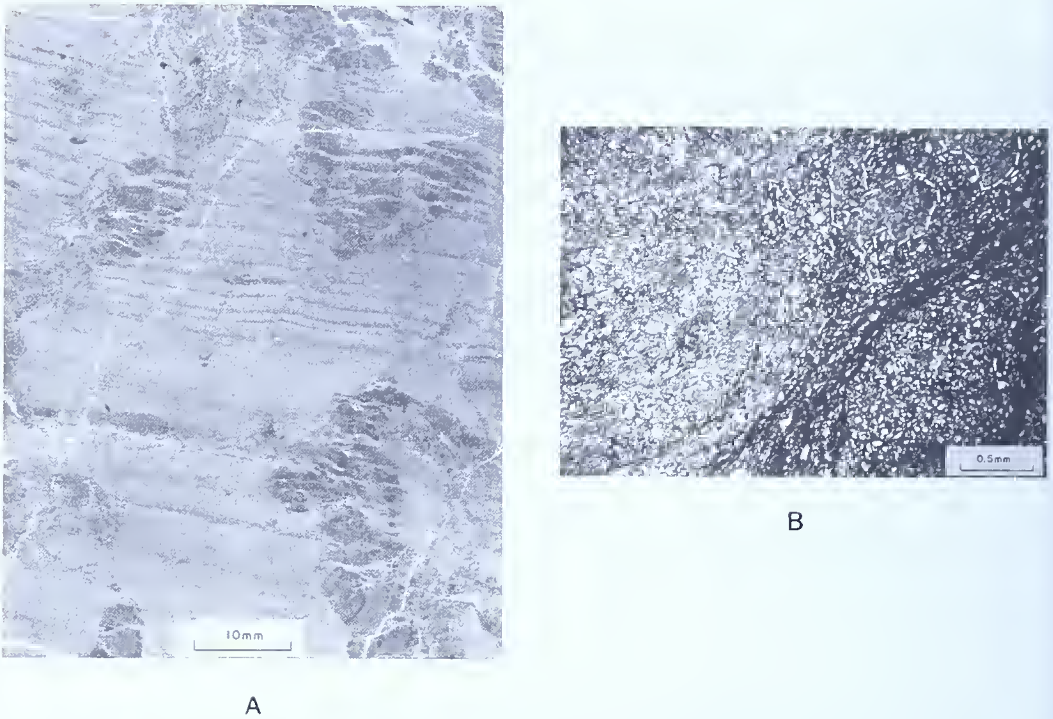


Figure 44. Ferroan dolomite concretions in Bloomsburg Red Beds. A. Negative print of acetate peel showing concretionary masses (dark) that apparently formed by replacement of host laminated shaly siltstone and shale. Rising solutions spread out laterally and replaced rock parallel to laminae. Unit 87 of section 3, Epstein and Epstein, 1972, p. 31–41. B. Photomicrograph (plane-polarized light) of irregular granoblastic ferroan dolomite concretion on left (diffuse boundary outlined) replacing hematitic shaly siltstone in unit 81 of section 3, Epstein and Epstein, 1972, p. 31–41. Note cleavage folia deflected slightly by concretion.

The red sandstones in the Bloomsburg are generally very fine to medium grained, but a few beds are coarse to very coarse grained or conglomeratic (quartz pebbles are as much as ¼ inch long). Beds are less than 4 inches to more than 5 feet thick. The sandstones are quartzitic, limonitic, and hematitic, and are planar bedded to crossbedded. Ripple marks are common. Red shale and siltstone intraclasts, as much as 3 inches across, are common (Figure 45). The basal 1-2 inches of several sandstones are medium gray (N5). These bases are generally abrupt and sandstone fills channels of very low relief in underlying siltstone or shale. A few sandstone beds may grade into underlying finer grained rocks. The sharp basal contact of some sandstones is accentuated by bedding-plane slippage, indicated by slickensides (Figure 45). Scattered small sandstone dikes extend through shale and siltstone connecting sandstone beds (Figure 46). The dikes average about 2 inches long and ¼ inch thick. Similar clastic dikes were noted in the Catskill Formation in central

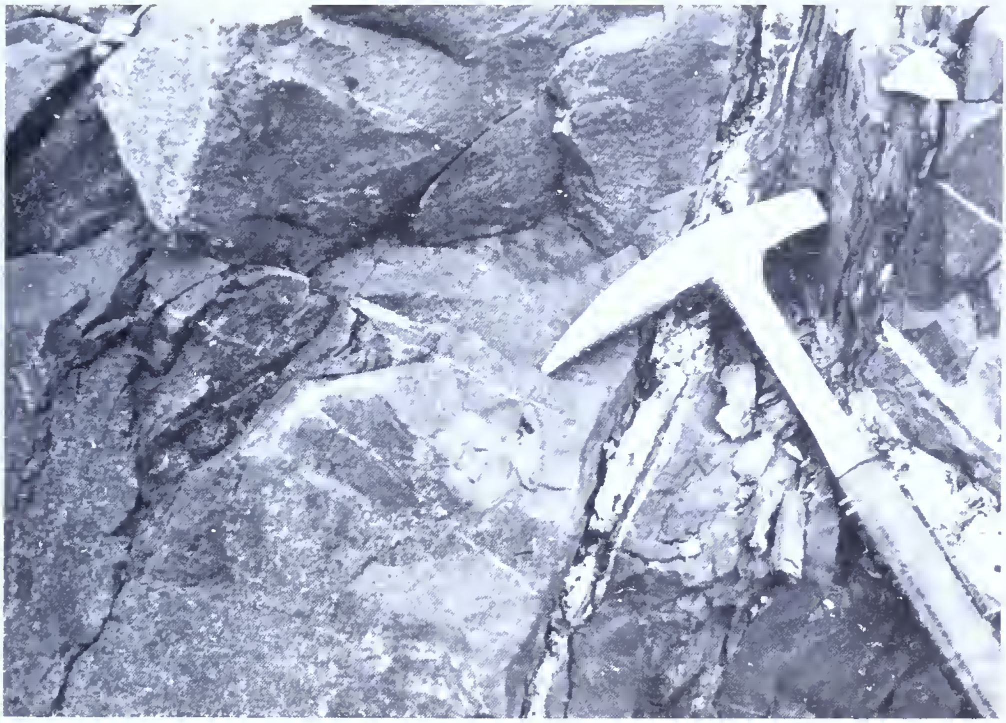


Figure 45. Red shale intraclast (near point of hammer) in coarse-grained crossbedded red sandstone, Bloomsburg Red Beds, Lehigh Gap, unit 91 of section 3, Epstein and Epstein, 1972, p. 31–41. Note slickensides (white) at base of sandstone.

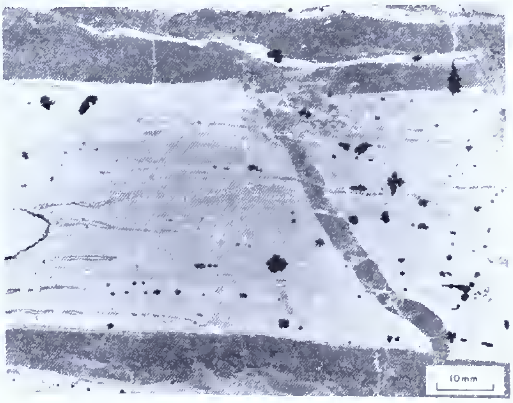


Figure 46. Sandstone dike (dark vertical structure) extending from red very fine to fine-grained sandstone at base through laminated silty shale, into sandstone. Near top of exposed Bloomsburg Red Beds at Lehigh Gap, unit 91 of section 3, Epstein and Epstein, 1972, p. 31–41. Negative print of acetate peel. Black patches are air bubbles in the peel.

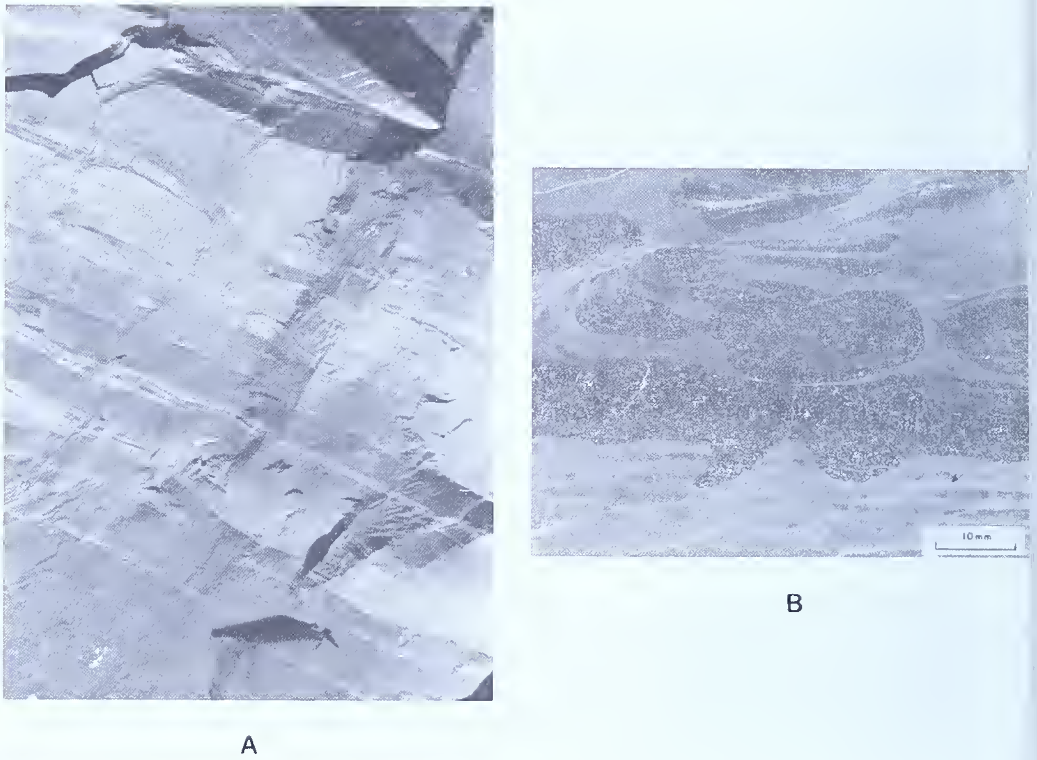


Figure 47. Laminated siltstone and sandstone, about 80 feet above base of Bloomsburg Red Beds, Lehigh Gap, unit 80 of section 3, Epstein and Epstein, 1972, p. 31–41. A. Laminated medium-greenish-gray siltstone (dark) and partly flaser-bedded light-greenish-gray fine-grained sandstone (light). Partly convoluted sandstone near top shown in detail in B. Tip of hammer at top gives scale. B. Disrupted bedding due to slump of mud and sand. Sand was disrupted during movement and separated by pinching and swelling into irregular discoid lumps as much as 2 inches long and ½ inch thick (sedimentary boudinage). Some of the sand lumps have complex flowage folds, and a few are nearly completely surrounded by clay laminae, indicating that the mud adhered to the sand as the sand rolled on the mud substrate; the sand was more mobile than the mud. Downward projections in lower half are probably load casts. Negative print of acetate peel.

Pennsylvania by Wells (1969), who interpreted them to have formed in alluvial overbank and crevasse splay deposits. This interpretation is similar to the one proposed here for the Bloomsburg (see section on environments of deposition).

Nonred beds are rare in the exposed Bloomsburg except in the lower 162 feet. These are as much as 3.5 feet thick and are light-greenish-gray (5GY7/1) to dark-greenish-gray (5GY4/1) and medium-light-gray (N6) to medium-bluish-gray (5B6/1) siltstone to medium-grained sandstone and minor medium-gray (N5) shale. They are interbedded or interlaminated with red beds and may also contain red mottles. Colors change laterally within a few tens of feet, apparently independently of grain size in most outcrops. Flaser bedding (ripple lensing) and primary slump structures are found in some beds (Figure 47).

The rocks in the Bloomsburg occur in poorly to well-defined upward-fining cycles (Figure 48). At Lehigh Gap, there are probably more than 50 cycles. These are between 0.5 and 13.3 feet thick and consist of fine- to very coarse grained crossbedded to planar-bedded sandstone that generally rests abruptly on and cuts into the underlying unit and grades up into thin-bedded, laminated, and ripple-laminated sandy siltstone and very fine to fine-grained sandstone, which, in turn, grades up into laminated and bioturbated sandy and shaly siltstone and silty shale that is mud cracked and contains irregular dolomite concretions. These cycles are thought to result from deposition by meandering streams (see discussion under section on environments of deposition).

Traces of malachite, chalcopyrite, and bornite were found in a ¼-inch-thick quartz vein parallel to a slickensided bedding plane and disseminated throughout a 24-foot-thick sequence about 140 feet above the base of the Bloomsburg (unit 86 of section 3, Epstein and Epstein, 1972, p. 31-41) (R. C. Smith II, Pa. Geol. Survey, written commun., 1973).

The Bloomsburg is not well exposed, except in Lehigh Gap, along the road through Little Gap, and along the Lehigh and New England Rail-

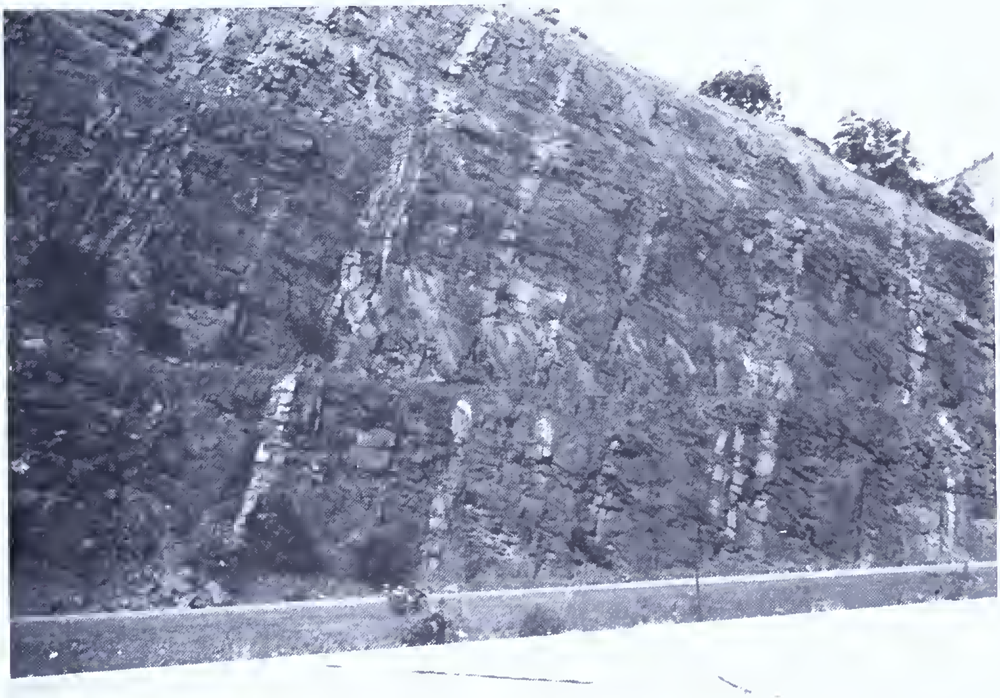


Figure 48. Alternating crossbedded to planar-bedded sandstone, irregularly laminated sandstone and siltstone, and laminated to bioturbated siltstone and shale in upward-fining cycles in the Bloomsburg Red Beds, Lehigh Gap. Stratigraphic top to left.

road. On the basis of construction of cross sections, the Bloomsburg is believed to be 1,300 to 1,700 feet thick (probably about 1,500 feet thick); only the lower 900 feet is exposed in Lehigh Gap (see section 3, Epstein and Epstein, 1972, p. 31-41). The formation is generally covered on the north slope of Blue Mountain and on the south slope of Stony Ridge in Palmerton. The base of the formation is placed at the base of the lowest red bed in a red, green, and gray transition zone between the Bloomsburg and the underlying Lizard Creek Member of the Shawangunk Formation. This transition zone is 162 feet thick at Lehigh Gap. The boundary between the Bloomsburg and the overlying Poxono Island Formation is also presumed to be transitional, as it is in the Delaware Water Gap area to the east (Epstein, 1971). There the contact is placed where the ratio of red beds to nonred beds is 1:1. The contact is very poorly exposed in the Lehighton and Palmerton quadrangles but is inferred by mapping of red and nonred float. Even so, this contact is conjectural in most places because of masking by weathered debris from the slopes above.

The rocks in the Bloomsburg are mineralogically, chemically, and

Table 4. *Chemical and Semiquantitative Spectrographic Analyses of Rocks from the Bloomsburg Red Beds*

Values above the double line are from the rapid-rock analyses by P. Elmore, G. Chloe, J. Kelsey, S. Botts, H. Smith, J. Glenn, and L. Artis, U.S. Geological Survey. Values, in parts per million, below double line are from semiquantitative spectrographic analyses by J. L. Harris, U.S. Geological Survey. N, not detected or at limit of detection; L, detected but below limit of determination. The following elements were looked for and not detected or were found in amounts at the limit of detection: Ag, As, Au, Bi, Cd, Eu, Ge, Hf, In, Li, Mo, Nd, Pd, Pr, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, U, W, Zn.

| | 1 | 2 | 3 |
|---|---|---|---|
| $SiO_2$ | 73.4 | 70.3 | 78.5 |
| $Al_2O_3$ | 12.1 | 15.7 | 6.2 |
| $Fe_2O_3$ | 4.8 | 1.6 | 5.9 |
| FeO | .92 | 1.8 | .20 |
| MgO | .82 | 1.4 | 1.5 |
| CaO | .17 | .15 | 1.5 |
| $Na_2O$ | .45 | .54 | .76 |
| $K_2O$ | 3.0 | 3.1 | 1.1 |
| $H_2O-$ | .22 | .24 | .14 |
| $H_2O+$ | 2.2 | 3.0 | 1.1 |
| $TiO_2$ | 1.0 | 1.2 | .41 |
| $P_2O_5$ | .08 | .04 | .04 |
| MnO | .04 | .02 | .25 |
| $CO_2$ | <.05 | <.05 | 1.8 |
| Total (percent) | 99.2 | 99.1 | 99.4 |

Table 4. *(Continued)*

| | 1 | 2 | 3 |
|---|---|---|---|
| B | 100 | 100 | L |
| Ba | 300 | 300 | 200 |
| Be | 2 | 3 | N |
| Co | 15 | 20 | 15 |
| Cr | 50 | 20 | 20 |
| Cu | 30 | 300 | 7 |
| La | 50 | 70 | N |
| Nb | 20 | 20 | 7 |
| Ni | L | 50 | 30 |
| Pb | 2 | 1 | 1 |
| Sc | 10 | 10 | 5 |
| Sr | 50 | 70 | 70 |
| V | 70 | 100 | 50 |
| Y | 50 | 30 | 20 |
| Zr | 700 | 500 | 100 |
| Ce | 300 | 300 | 100 |
| Ga | 15 | 15 | 7 |
| Yb | 5 | 3 | 2 |

1. Grayish-red (5R4/2) shaly siltstone, about 120 feet above base of Bloomsburg Red Beds (unit 83, section 3, Epstein and Epstein, 1972, p. 31–41), roadcut along Pa. Route 248.
2. Laminated greenish-gray (5GY6/1) shale to very fine grained sandstone, about 150 feet above base of Bloomsburg Red Beds (unit 86, section 3, Epstein and Epstein, 1972, p. 31-41), roadcut along Pa. Route 248.
3. Very coarse grained feldspathic and lithic graywacke, 545 feet above base of Bloomsburg Red Beds (unit 91, section 3, Epstein and Epstein, 1972, p. 31-41), roadcut along Pa. Route 248. Figure 50 shows photomicrographs of the rock.

texturally immature (low percentage of silica in chemical analyses, Table 4). Six samples of shale and siltstone from the Bloomsburg were analyzed by X-ray diffraction. These averaged about 55 percent quartz (range, 40-70 percent), 40 percent muscovite (range, 25-50 percent), 5 percent chlorite (range, <5-15 percent), and probably less than 1 percent feldspar.

In thin section, the sandstones are mostly graywackes with appreciable rock fragments and feldspar. Most rocks contain abundant hematite coating the framework grains. The hematite is probably an alteration product of chlorite, because much of the chlorite that is present is partly altered to hematite. Most of the framework grains are angular, especially in the finer grained rocks. Feldspar, which is rare to absent in the rocks in the underlying Shawangunk Formation, is common in all thin sections of sandstone studied, and many rocks are feldspathic graywackes (Figures 49 and 50). Plagioclase is the most common type, but potash feldspar and

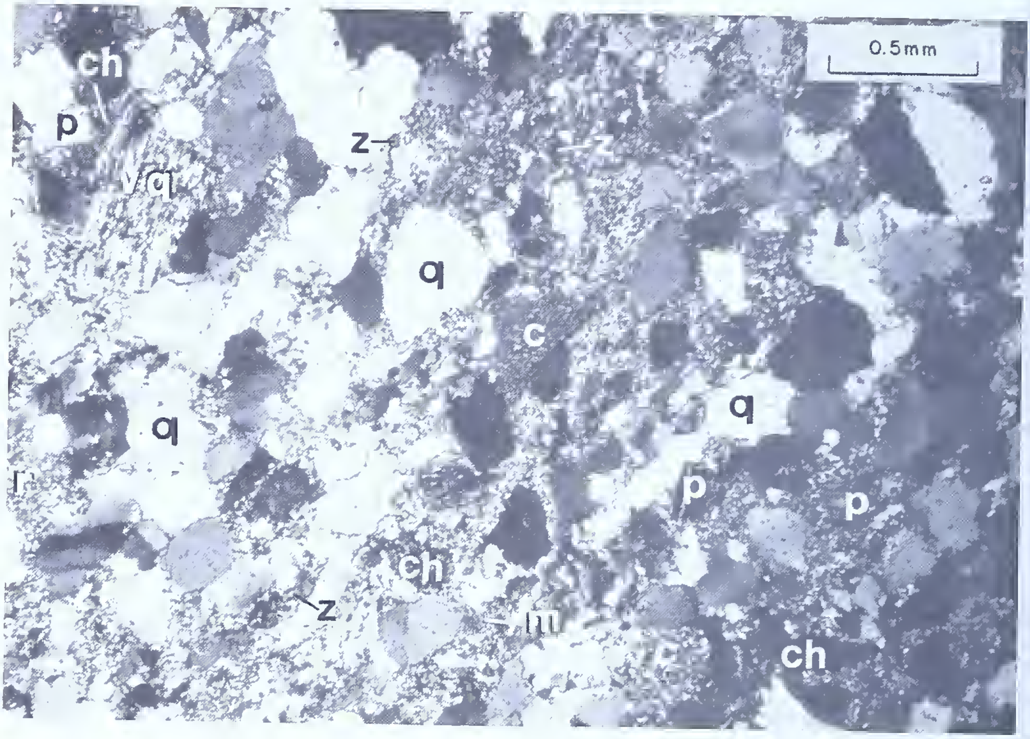
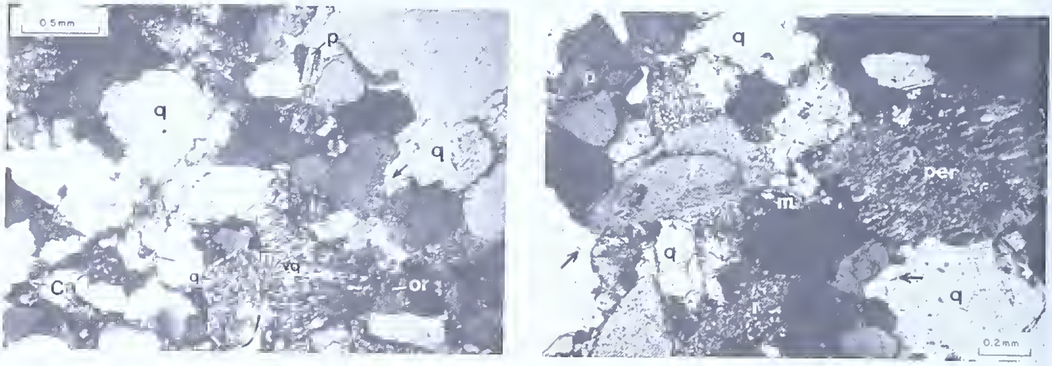
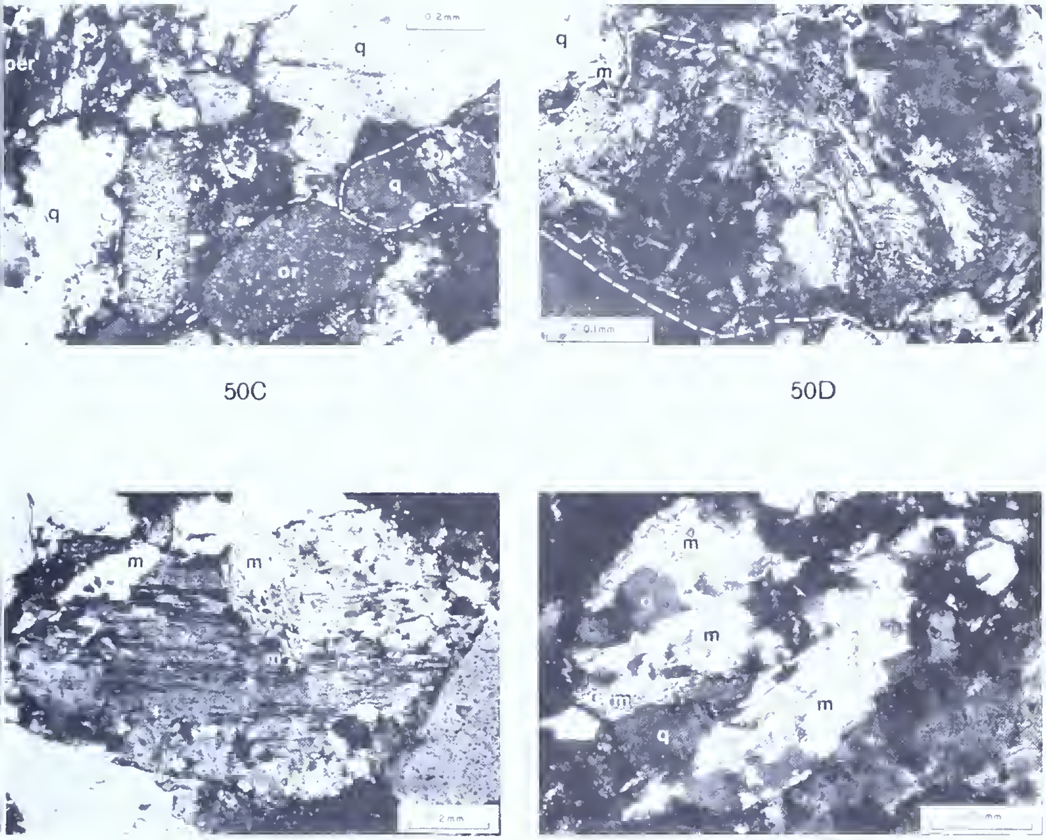


Figure 49. Photomicrograph (crossed polarizers) of fine-grained feldspathic graywacke, Bloomsburg Red Beds, unit 86 of section 3, Epstein and Epstein, 1972, p. 31–41. Quartz (78 percent) occurs mostly as single grains (q) having straight to undulose extinction and as minor semicomposite grains that are probably vein quartz (vq), but which may be stretched metamorphic grains. Chert (c, 1 percent) is angular to subrounded. Plagioclase (p, 2 percent) is generally angular to subangular. Shale fragments (r) and muscovite (m) make up about 1 percent of the rock. Zircon (z) and tourmaline, generally euhedral to subrounded, are scattered throughout. The fine silt-sized matrix (17 percent) is made up mostly of quartz and muscovite and lesser chlorite. Chlorite (ch, 1 percent) fills many pores.



50A

50B



50C

50D

50E

50F

Figure 50. Photomicrographs (crossed polarizers) of poorly sorted coarse-grained feldspathic and lithic graywacke from unit 91 of section 3, Epstein and Epstein, 1972, p. 31–41, Bloomsburg Red Beds, Lehigh Gap. As shown in A, B, and C, the rock consists of quartz (70 percent; angular to subrounded single grains (q) with undulose extinction are most common, with lesser vein quartz (vq); many overgrowths (arrows) and interlocking grain borders; many grains rimmed with hematite), chert (c, 1 percent), muscovite (m, 1 percent), feldspar (3 percent; plagioclase (p, probably albite-oligoclase), orthoclase (or), and perthite (per); all sericitic, in part); rock fragments (4 percent), mostly shale (r), but some igneous rock fragments (outlined in A and C), and scattered subrounded to euhedral zircon and tourmaline, as well as black opaque minerals. These grains are enclosed in a hematite-rich matrix (17 percent) of finer grained quartz and muscovite, and in iron-stained carbonate cement (Ca, 2 percent), and silica overgrowths (2 percent). Other than the shale, the rock fragments consist of felsite (outlined in A) consisting of lath-shaped plagioclase (p), quartz (q), and finer muscovite. D is an enlargement of a similar grain showing plagioclase laths and probably spherulitic quartz; note replacement by muscovite (m) along interlocking border with quartz grain (q). Outlined in C is a grain of intergrown quartz (q) and plagioclase (p). E is an enlargement of muscovite (m) in a grain of perthite. F shows a grain of intergrown muscovite (m) and quartz (q). The felsite grains, and grains of feldspar intergrown with quartz and muscovite, show that the source rocks may have been volcanic as well as granitic or gneissic.

perthitic intergrowths were seen in a few samples (Figure 50). The feldspar grains are angular to subangular and do not appear to exceed about 4 percent of the minerals in rocks of the Bloomsburg.

Rock fragments were found in all samples examined (as much as 4 percent of some), and many rocks are lithic graywackes (Figure 51). The rock fragments are mostly shale and siltstone, but micaceous quartzite (Figure 51), felsite (Figure 50A, D), and granitic or gneissic grains of intergrown feldspar, quartz, and muscovite (Figure 50C, E, F) are found in minor amounts.

Quartz in the sandstones is angular to subrounded and generally occurs as single crystals having slightly to strongly undulose extinction, although semicomposite grains (mostly vein quartz) may be common. Silica overgrowths are abundant and are separated from the parent grain by a thin coating of hematitic clay in many cases. Interlocking grain contacts are also common; these may be sutured. Many quartz grains are partly

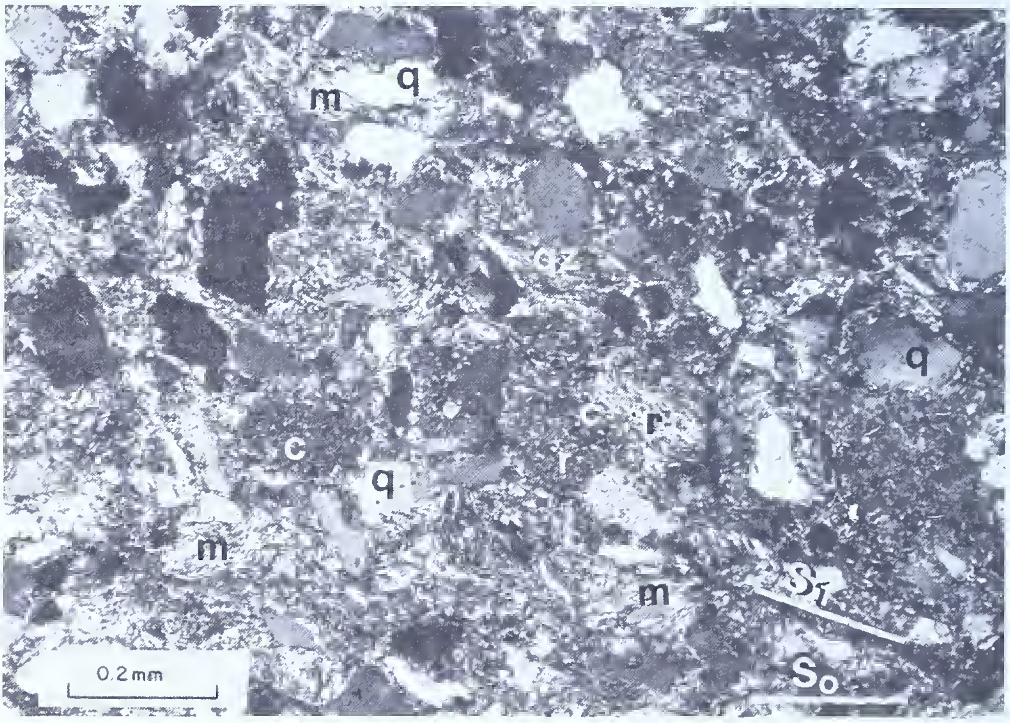


Figure 51. Photomicrograph (crossed polarizers) of lithic graywacke, 80 feet above the base of the Bloomsburg Red Beds, Lehigh Gap, unit 80 of section 3, Epstein and Epstein, 1972, p. 31–41. The rock consists predominantly of angular and corroded quartz (q, 48 percent), lesser chert (c, 5 percent), muscovite (m, 6 percent), biotite (1 percent), shale rock fragments (r, 1 percent), and micaceous quartzite (qz, <1 percent) in a finer muscovite-quartz-chlorite matrix (39 percent). Some muscovite and quartz are elongated parallel to cleavage ($S_1$) which is at an angle of about 23° to bedding ($S_0$).

replaced by muscovite and chlorite, having reacted with the matrix. Quartz does not exceed 80 percent of the rocks in the thin sections examined.

Sand-sized muscovite, biotite, rounded to subrounded chert, and chlorite make up minor components of all rocks. The chlorite is probably mostly penninite because it has anomalous purple and blue interference colors. It also occurs as spherulitic pore fillings and is partly intergrown with muscovite. Some chlorite grains are concentrated in argillaceous sandstone laminae and are several times larger than other grains, suggesting that they are products of recrystallization rather than detrital. In many samples, chlorite is partly replaced by hematite.

The nonopaque heavy minerals, besides the muscovite, biotite, and chlorite, include only subrounded to euhedral zircon and blue, green, and brown tourmaline. Iron-stained (sideritic?) calcite replaces some quartz and fills interstices in a few samples.

The matrix of the sandstones in the Bloomsburg constitutes not less than 15 percent of most rocks and consists of clay- and silt-sized muscovite and quartz and lesser chlorite mixed with hematite.

No fossils have been found in the Bloomsburg in the report area, but fish scales and fish fragments have been collected between Wind Gap and Delaware Water Gap to the east (Beerbower and Hait, 1959). These fossils ought to be present in the Lehighton and Palmerton quadrangles. The Bloomsburg in eastern Pennsylvania cannot be directly dated by fossils, but it is believed to be Middle and Late Silurian in age (Swartz and others, 1942) or latest Wenlockian to early Pridoli of Berry and Boucot (1970). This is in agreement with the physical tracing of the Bloomsburg into the Lockport Group (Middle Silurian) and Vernon Shale (Upper Silurian) of central New York by Rickard (1969).

## Poxono Island Formation

The Poxono Island Formation is very poorly exposed in the map area—only two nonslumped outcrops were found, both in the Lehighton quadrangle. The unit was named the Poxono Island Shale by White (1882) for at least 200 feet of buff, green, and variegated nonfossiliferous limy shales exposed on the north bank of the Delaware River near Poxono Island, about 7 miles northeast of Delaware Water Gap. These rocks were included in the Scalent Formation of Rogers (1858) and, north of Lehigh Gap, were termed the Water Lime Shales by Chance (1882a).

The best outcrops of the Poxono Island Formation are along the railroad cut of the Central Railroad of New Jersey (measured section 1), where the upper 31 feet of the formation is exposed. Swartz and Swartz (1941) measured 212 feet when the section was better exposed, but they did not see the base. The Poxono Island at this locality consists of laminated to finely bedded, partly mud-cracked and lenticular dolomite, limestone, and calcareous shale (Figures 52 and 53). Micro scour-and-fill is common, and bedding may be indistinct because of burrow mottling. Pyrite is scattered throughout. The dolomite is partly calcareous and argillaceous, greenish gray (5GY6/1), and light-bluish gray (5B7/1), and weathers dark-yellowish orange (10YR6/6) to pale-yellowish orange (10YR8/6). It is ferroan dolomite (ankerite), as indicated by a blue stain when treated with potassium ferricyanide. The limestone is argillaceous, very fine to fine grained, and medium-light gray (N6) to medium-dark gray (N4). It weathers light gray (N7) to medium-light gray (N6). Shale intraclasts as much as 1.5 inches long are not common. Thin beds and laminae may grade upward from ostracode-rich quartzose calcarenites (Figure 54) and calcareous sandstones, through finer limestone, into greenish-gray (5GY6/1) and grayish-green (10GY5/2) to pale-olive

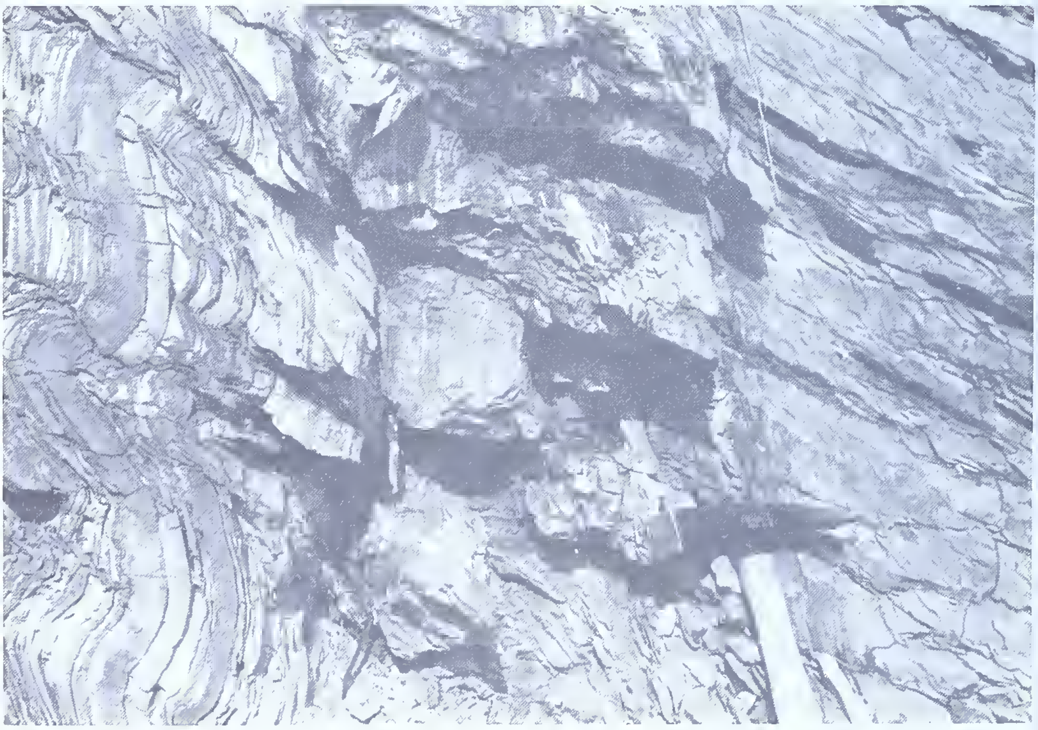


Figure 52. Laminated and thin-bedded dolomite, limestone, and shale to left of hammer (unit 7 of measured section 1) resting on mud-cracked dolomite (top of unit 6 of measured section 1) in the Poxono Island Formation, Central Railroad of New Jersey southeast of Bowmanstown. Note graded beds in unit 7 and also cleavage that dips moderately to the southeast (to lower right) and the generally more complex folds in the finer grained beds. Some of the lighter beds in the upper left have been thinned by removal of limestone along cleavage.

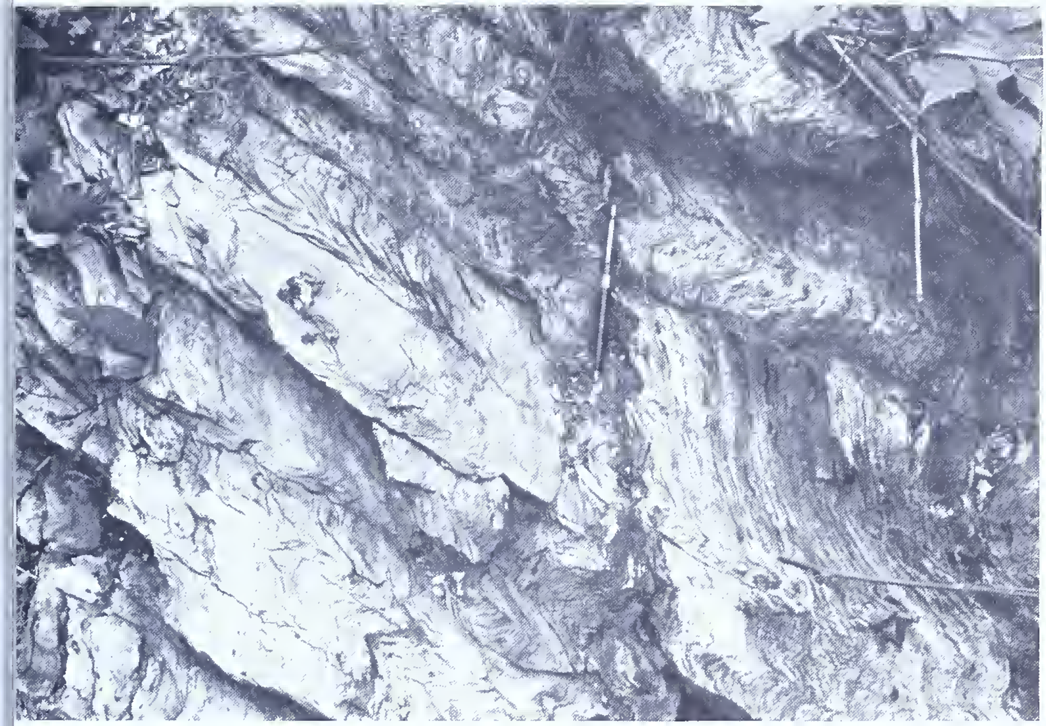


Figure 53. Laminated limestone and calcareous shale in the Poxono Island Formation along Central Railroad of New Jersey. Rock to left of pen is mud cracked and overlies similar rock that is not mud cracked. Axes of small folds and regional cleavage are about parallel to mud-crack columns. Units 9 and 10 of measured section 1.

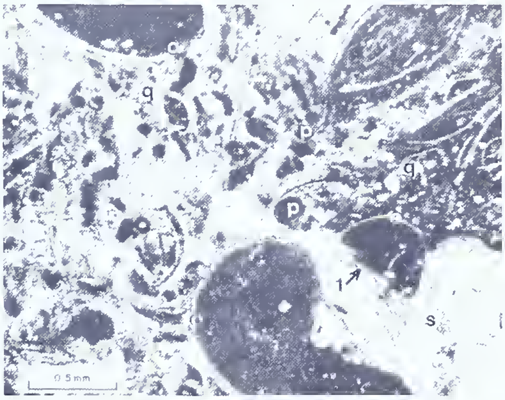


Figure 54. Photomicrograph (plane-polarized light) of ostracode biosparrudite, upper part of Poxono Island Formation, cut along Central Railroad of New Jersey, unit 2 of measured section 1. Sample is from base of lamina that grades up into micrite. Fossils shown are all leperditiid ostracodes (o) (filled with silty micrite), but ornate forms are present elsewhere on the slide. Pellets (p) and etched silt-sized quartz grains (q) are common. The rock may initially have been a biopelmicrudite, because the spar (s) may be pseudospar as it appears to cut across some fossils (at 1, for example).

(10Y6/2) and light-gray (N7) to medium-gray (N5) shale that weathers grayish orange (10YR7/4) to dark-yellowish orange (10YR6/6). Fossils include mostly leperditiid and lesser ornate ostracodes and rare brachiopod fragments.

The Poxono Island Formation was reached in the Phillips Petroleum Company exploration well No. 1 Graver Estate (see measured section 24) at a depth of 5,255 feet and extends at least 141 feet to a depth of 5,396 feet to the bottom of the hole. It consists of light-greenish-gray to pale-green shale and dolomite, as well as interbedded very light gray to pale-green, very fine grained argillaceous, silty, and dolomitic limestone with traces of anhydrite and pyrite.

The U.S. Army Corps of Engineers drill hole, 300 feet south of the road at Walkton, bottomed in 10 feet of Poxono Island Formation consisting of red and grayish-green shale and partly dolomitic light-brown to bluish-green limestone beneath 66 feet of surficial deposits.

In thin section, most rocks of the Poxono Island are finely laminated to finely bedded and graded. Basal beds and laminae of graded sequences are biomicrudites and biosparrudites (Figures 54 and 55) that may be pelletal. Pseudospar has formed to varied degrees, and some rocks that appear to be sparites may actually be neomorphosed micrites. Fragmented and entire ostracode carapaces are abundant in the basal beds and become scarcer upwards. Silty quartzose pelsparites and pelmicrites overlie the basal beds, and these are succeeded by micrites. The quartz in these rocks is angular and generally etched. Sparse plagioclase, probably albite, and subrounded zircon and tourmaline were seen. The dolomite appears to have replaced previously deposited limestone.

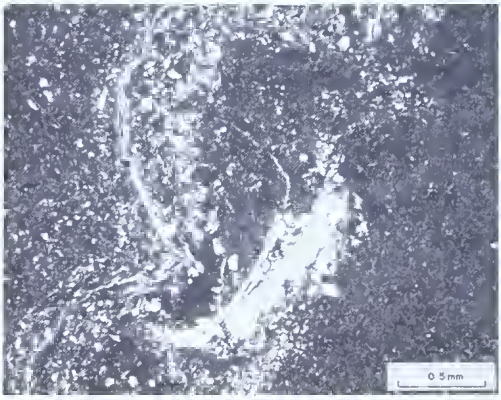


Figure 55. Photomicrograph (crossed polarizers) of silty ostracode biomicrudite at base of graded bed resting on micrite at top of another graded bed. Stratigraphic top is to left. Upper part of Poxono Island Formation, cut along Central Railroad of New Jersey, unit 7 of measured section 1. See Figure 52 for photograph of exposure of this rock.

Chemical analyses of a laminated calcareous shale and limestone and an argillaceous calcareous dolomite are given in Table 5. X-ray analyses (Figure 56A) show that the dominant minerals in rocks of the Poxono Island are calcite, dolomite (not seen in the diffractogram in Figure 56A), muscovite, and quartz, and lesser chlorite and montmorillonite (which occurs in mixed-layer illite-montmorillonite), as well as some pyrite. The occurrence of montmorillonite in the Poxono Island Formation, as well as in the Bossardville Limestone and Decker Formation, was unexpected because it is generally believed that montmorillonite does not persist

Table 5. *Chemical and Semiquantitative Spectrographic Analyses of Rocks from the Poxono Island Formation, Bossardville Limestone, and Decker Formation*

Values above the double line are from the rapid-rock analyses by P. Elmore, G. Chloe, J. Kelsey, S. Botts, H. Smith, J. Glenn, and L. Artis, U.S. Geological Survey. Values, in parts per million, below double line are from semiquantitative spectrographic analyses by J. L. Harris, U.S. Geological Survey. N, not detected or at limit of detection; L, detected but below limit of determination. The following elements were looked for and not detected or were found in amounts at the limit of detection: Ag, As, Au, Bi, Cd, Eu, Ge, Hf, In, Li, Mo, Nd, Pd, Pr, Pt, Re, Sb, Sm, Sn, Ta, Te, Th, Tl, U, W, Zn.

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ | 40.8 | 28.8 | 5.2 | 26.5 | 67.1 |
| $Al_2O_3$ | 9.1 | 8.3 | 1.5 | 4.8 | 13.7 |
| $Fe_2O_3$ | 2.3 | 1.7 | .34 | 1.1 | 2.9 |
| FeO | 1.8 | 3.3 | .56 | 2.8 | 1.7 |
| MgO | 2.4 | 10.6 | .84 | 5.6 | 1.7 |
| CaO | 20.6 | 17.3 | 49.6 | 26.9 | 2.8 |
| $Na_2O$ | .36 | .19 | .16 | .38 | .72 |
| $K_2O$ | 2.3 | 2.3 | .32 | 1.1 | 3.2 |
| $H_2O-$ | .27 | .26 | .09 | .13 | .41 |
| $H_2O+$ | 2.3 | 2.4 | .60 | 2.1 | 2.5 |
| $TiO_2$ | .61 | .41 | .06 | .34 | .97 |
| $P_2O_5$ | .07 | .06 | .01 | .04 | .07 |
| MnO | .06 | .11 | .08 | .17 | .05 |
| $CO_2$ | 16.2 | 23.5 | 40.5 | 28.0 | 2.0 |
| Total (percent) | 99.2 | 99.2 | 99.9 | 100.0 | 99.8 |
| B | 50 | 50 | N | 30 | 150 |
| Ba | 200 | 150 | 50 | 100 | 300 |
| Be | 1 | 1 | N | N | 3 |
| Co | 20 | N | N | N | 20 |
| Cr | 50 | 20 | 3 | 20 | 70 |
| Cu | 15 | 10 | 7 | 15 | 20 |
| La | 100 | N | N | N | 100 |

Table 5. (*Continued*)

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Nb | 7 | 7 | N | N | 20 |
| Ni | 30 | L | L | L | 50 |
| Pb | 2 | 2 | 3 | 2 | 2 |
| Sc | 10 | 7 | N | 3 | 10 |
| Sr | 1000 | 500 | 1000 | 500 | 70 |
| V | 50 | 20 | 15 | 15 | 70 |
| Y | 50 | 20 | 10 | 30 | 50 |
| Zr | 150 | 30 | 30 | 50 | 500 |
| Ce | 200 | 100 | N | 100 | 500 |
| Ga | 15 | 15 | 1 | 7 | 20 |
| Yb | 5 | 2 | 1 | 3 | 5 |

1. Poxono Island Formation, laminated calcareous shale and limestone, about 25 feet below top of formation (unit 4 of measured section 1), railroad cut along Central Railroad of New Jersey, 3,500 feet southeast of intersection of Pa. Routes 895 and 248 in Bowmanstown.
2. Poxono Island Formation, uppermost bed, argillaceous calcareous dolomite (unit 12 of measured section 1), railroad cut along Central Railroad of New Jersey, 3,500 feet southeast of intersection of Pa. Routes 895 and 248 in Bowmanstown.
3. Bossardville Limestone, medium-grained fossiliferous limestone, 7 feet below top of formation (unit 7 of measured section 2), abandoned quarry, 1,500 feet northeast of Hazard School in Palmerton.
4. Decker Formation, laminated slightly dolomitic limestone and shaly limestone, 4 feet above base of formation (unit 17 of measured section 2), abandoned quarry, 1,500 feet northeast of Hazard School in Palmerton.
5. Decker Formation, very fine grained slightly calcareous silty sandstone, about 23 feet above base of formation (unit 20 of measured section 2), abandoned quarry, 1,500 feet northeast of Hazard School in Palmerton.

in such old rocks (see Pettijohn, 1957, p. 137). These units contain abundant magnesium in the form of dolomite and calcium in calcite. No montmorillonite has been found in the rocks of the Lizard Creek Member of the Shawangunk Formation, which contains rare or no dolomite and little calcite. All these rocks are interpreted to have been deposited in a similar nearshore environment (see section on environments of deposition). It is possible, therefore, that the $Ca^{++}$ and $Mg^{++}$ available in the Poxono Island-Decker interval, as well as $Na^{++}$ available in sea water, favored the formation of montmorillonite (possibly originally in mixed-layer illite-montmorillonite), and that $K^{+}$ may have replaced some $Ca^{++}$, forming mixed-layer illite-montmorillonite.

Green beds are characteristic of the Poxono Island Formation, although red shales and siltstones are interbedded lower in the section as the transitional boundary with the Bloomsburg Red Beds is approached. What is believed to be this boundary is exposed only in a creek 600 feet

EXPLANATION

— - — - —
Whole rock sample

Clay-sized sample (< 2 microns) treated
in dilute acetic acid to remove carbonates

———————
Untreated, oriented

— — — —
Heated, 300°C

- - - - - - - - - - - - - -
Glycolated

C, Calcite
D, Dolomite
M, Muscovite
Q, Quartz
Ch, Chlorite
K, Kaolinite
P, Pyrite
Mt, Montmorillonite, shown on glycolated trace
ML, Mixed-layer (mostly illite-montmorillonite)

A. Poxono Island Formation. Silty pyritic laminated limestone
Unit 2 of measured section 1
B. Bossardville Limestone. Argillaceous limestone. Unit 5 of
measured section 2.
C Decker Formation. Dolomitic laminae in shaly limestone.
Unit 17 of measured section 2.
D. Decker Formation. Arenaceous limestone. Unit 19 of
measured section 2.
E. Stormville Member of Coeymans Formation. Weathered
medium-grained sandstone. Unit 18 of measured section 3.

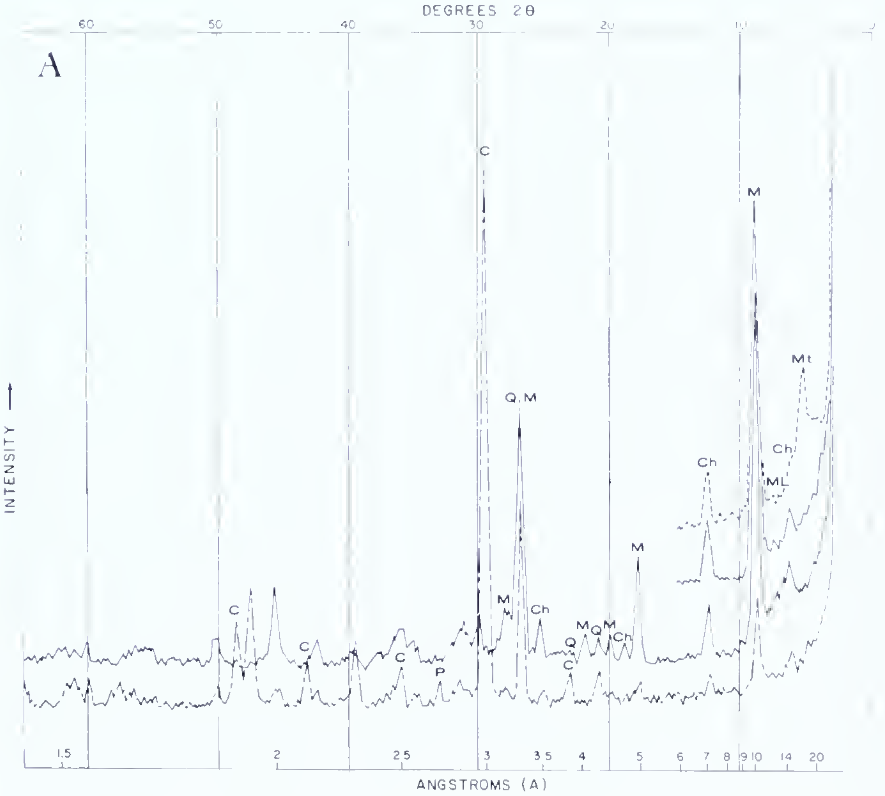


Figure 56. Typical X-ray diffractograms of carbonate rocks of the Poxono Island Formation, Bossardville Limestone, Decker Formation, and Stormville Member of the Coeymans Formation.

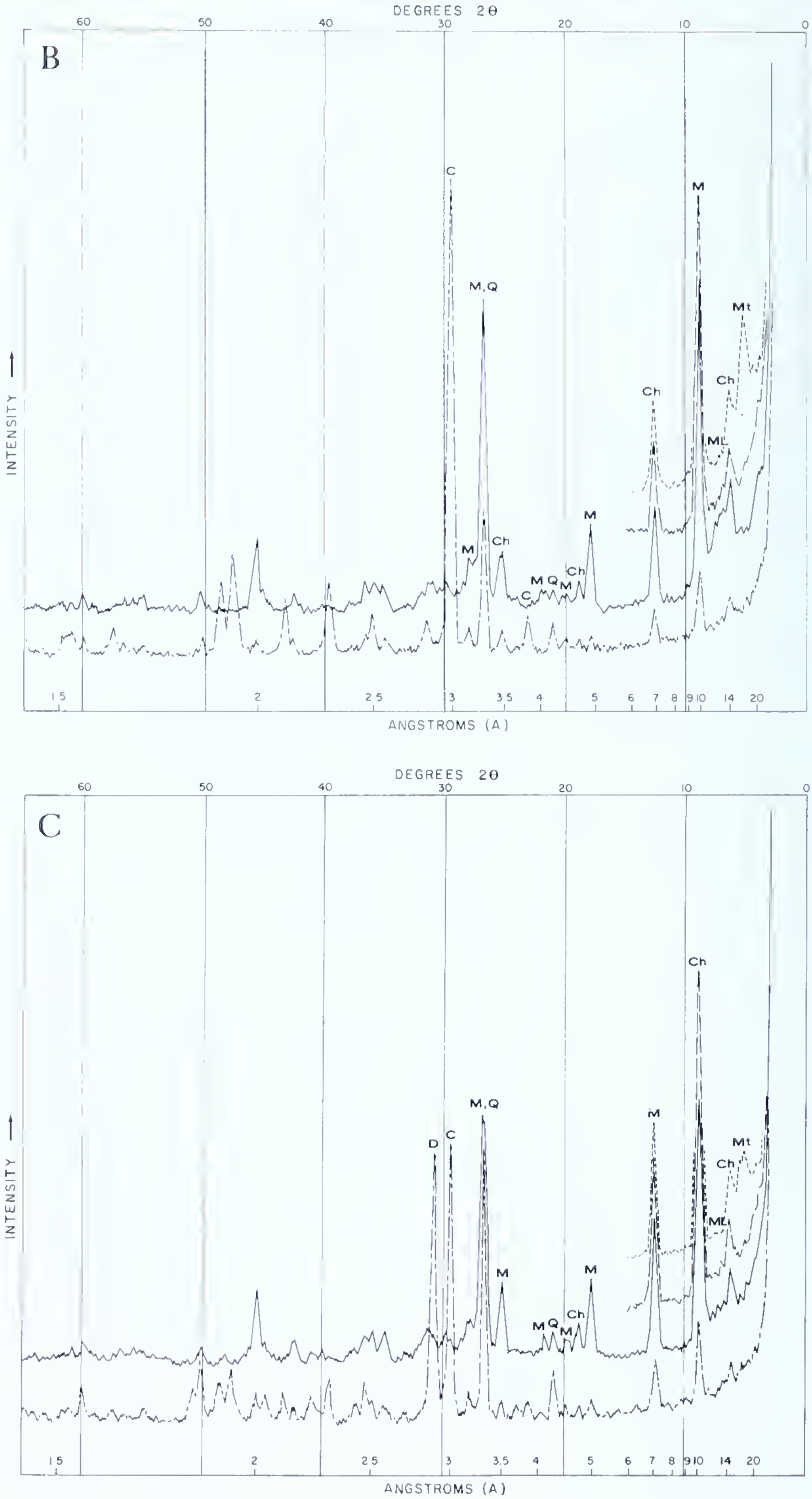


Figure 56. *(Continued)*

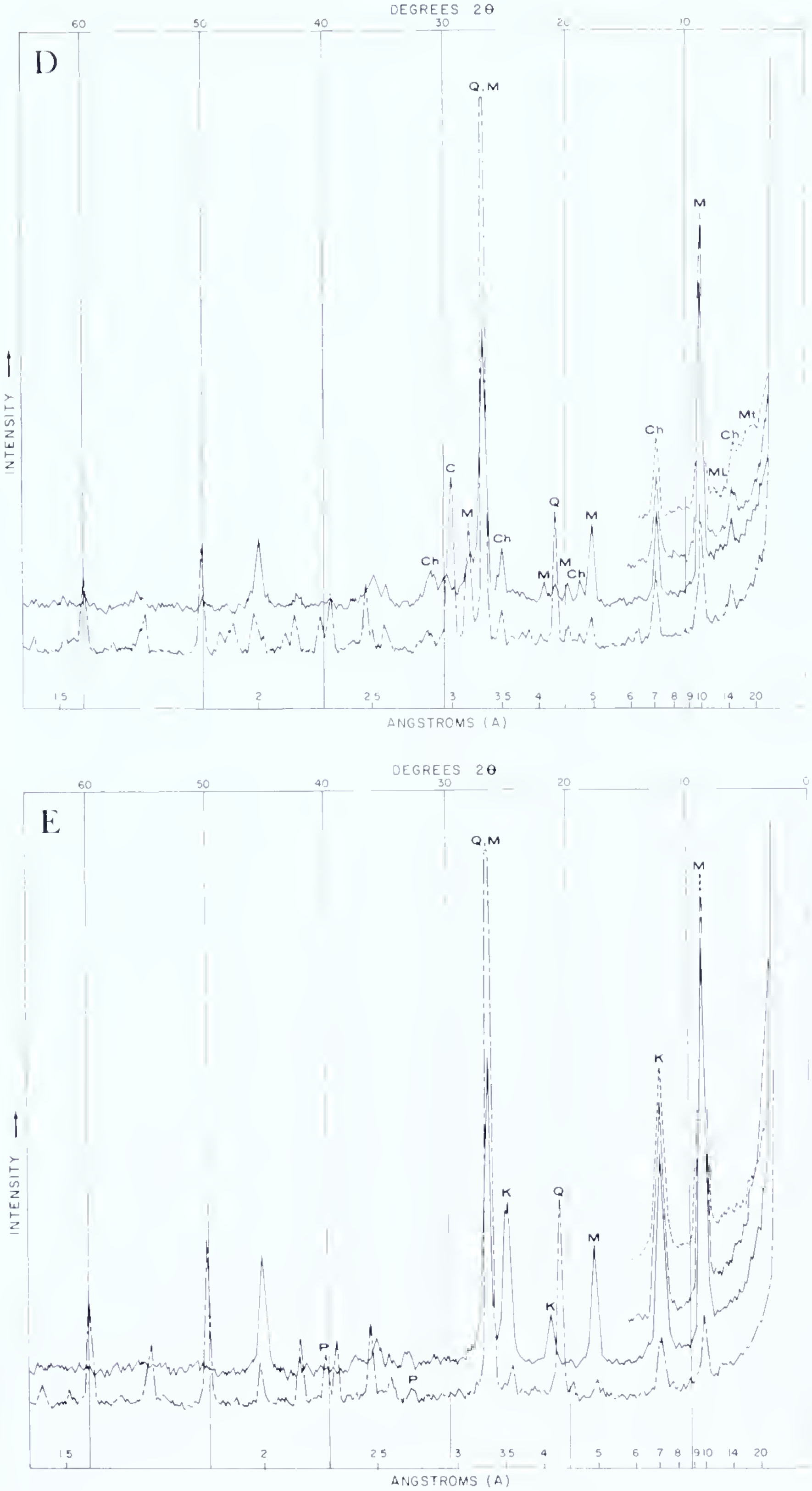


Figure 56. *(Continued)*

northeast of the Hazard School in Palmerton, Lehighton quadrangle. Here, about 10 feet of pale-red (5R6/2) shaly siltstone of the Bloomsburg is overlain by about 20 feet of medium-greenish-gray (5GY7/1) shaly siltstone of the Poxono Island. These rocks weather pale-yellowish orange (10YR8/6) to grayish orange (10YR7/4).

Green shales and siltstones are the most abundant rock types in the Poxono Island, judging from the scattered exposures and float. Swartz and Swartz (1941) reported at least 215 feet of predominantly shale in the Poxono Island in the Kline tunnel at Hazard, and Agthe and Dynan (1910) showed about 390 feet of shale in a cross section through the tunnel (their Figure 36, units 15-17).

The contact with the overlying Bossardville Limestone is placed at the top of the highest dolomite (Figure 57). This boundary was seen only along the tracks of the Central Railroad of New Jersey. So defined, the Poxono Island contains some limestone typical of the Bossardville.

The thickness of the Poxono Island varies tremendously because of structural thickening and thinning (see cross sections on Plate 1) and appears to range from about 300 feet to more than 800 feet. In a water well drilled for the New Jersey Zinc Company, Palmerton, Pennsylvania, the Poxono Island is about 300 feet thick (see measured section 4). It may average about 500-600 feet in thickness, more than an earlier estimate of 300-400 feet (Epstein and Epstein, 1969, p. 143). The Poxono Island, therefore, thins from about 700 feet in the Delaware Water Gap area, about 30 miles to the northeast (see Epstein and Epstein, 1967, Figure 4), to about 550 feet in the Lehigh Gap area, to a feather edge at the Schuylkill River, 25 miles to the southwest (Swartz and Swartz, 1941).

There are no diagnostic fossils in the Poxono Island, but the age of the formation is middle Late Silurian and it correlates with the Tonoloway Limestone of central Pennsylvania (Rickard, 1969).

## Bossardville Limestone

The type locality of the Bossardville Limestone is at Bossardsville, Pennsylvania, in Cherry Valley, about 15 miles northeast of the Palmerton quadrangle, where the limestone is extensively quarried. The Bossardville was named by White (1882), who did not designate a type section but who described (p. 240) the limestone at the north Croasdale quarry at the east end of Godfrey Ridge, 2.5 miles east of Stroudsburg, Pennsylvania. The Bossardville in the quarry is about 100 feet thick and consists of medium- to dark-gray, very fine to fine-grained, laminated to thin-bedded, partly argillaceous, sandy, and dolomitic limestone, and less abundant calcareous shale, siltstone, and dolomite (Epstein, 1973). The

Bossardville of easternmost Pennsylvania and New Jersey has been described by Epstein and others (1967).

In the Lehigh Gap area, the Bossardville was termed the Lewistown Limestone and the lower Helderberg Limestone by Chance (1882b, Plate 3, p. 358). He reported it to be 69 feet thick, but his boundaries were not definite. Agthe and Dynan (1910, Figure 36, units 13 and 14) illustrated 130 feet of limestone and limy shale in the Helderberg Limestone in the Kline tunnel at Hazard, Pennsylvania, that may be the Bossardville Limestone. Swartz and Swartz (1941, p. 1143) described 100 feet of the Bossardville at Andreas, Pennsylvania, 7 miles southwest of Lehighton.

In the Lehighton and Palmerton quadrangles, the Bossardville was seen during the present study at only two localities: 1) along the tracks of the Central Railroad of New Jersey where 9 feet of rock (measured section 1) is now exposed (44 feet of banded calcareous shale and shaly limestone was reported by Swartz and Swartz (1941, p. 1147), the top of the formation not exposed); and 2) in an abandoned quarry 1,500 feet northeast of the Hazard School in Palmerton, where 63 feet of the Bossardville was measured (section 2). At this place, however, 77 feet of rock with the base not exposed was reported by Swartz and Swartz (1941, p. 1152). The Bossardville underlies the low part of the rubble-veneered south slope of Stony Ridge in the report area. The best estimate of its thickness is 100 feet (Epstein and Epstein, 1967, 1969).

The Bossardville Limestone is made up mostly of limestone and lesser shale. The limestone is laminated to thin bedded (beds are as much as 4 inches thick) and has been called a "ribbon limestone" (Figures 57-59). Fresh colors are medium-light gray (N6) to dark gray (N3) and minor light-olive gray (5Y6/1) to medium-olive gray (5Y5/1). It weathers pale-yellowish orange (10YR7/3) to moderate-yellowish brown (10YR5/4), yellowish gray (5Y8/1) to pale-yellowish brown (10YR6/2), light gray (N7) to medium-light gray (N6), light-bluish gray (5B7/1), and light-olive gray (5Y6/1). The limestone is generally very fine to fine grained, but some is very coarse grained. It is generally argillaceous and silty, pyritic, and in parallel and wavy laminated beds. Grading is common, and coarser basal beds have a scoured lower surface. They are quartzose, generally rich in ostracodes, and contain some intraclasts as much as 1 inch long. Many intraclasts are encrusted with bryozoans and possibly algae (oncolites) (Figure 60). Ostracodes are less abundant in finer laminae. Burrow mottling was seen in some samples. Some beds are mud cracked (Figure 61); mud-crack polygons are as much as 10 inches wide and paper-thin dark-gray (N3) to medium-dark-gray (N4) shale fills the cracks. The mud cracks were compressed during folding, and the shale fillings were probably mobilized during the formation of rock cleavage, thus accentuating the shape of the columns.

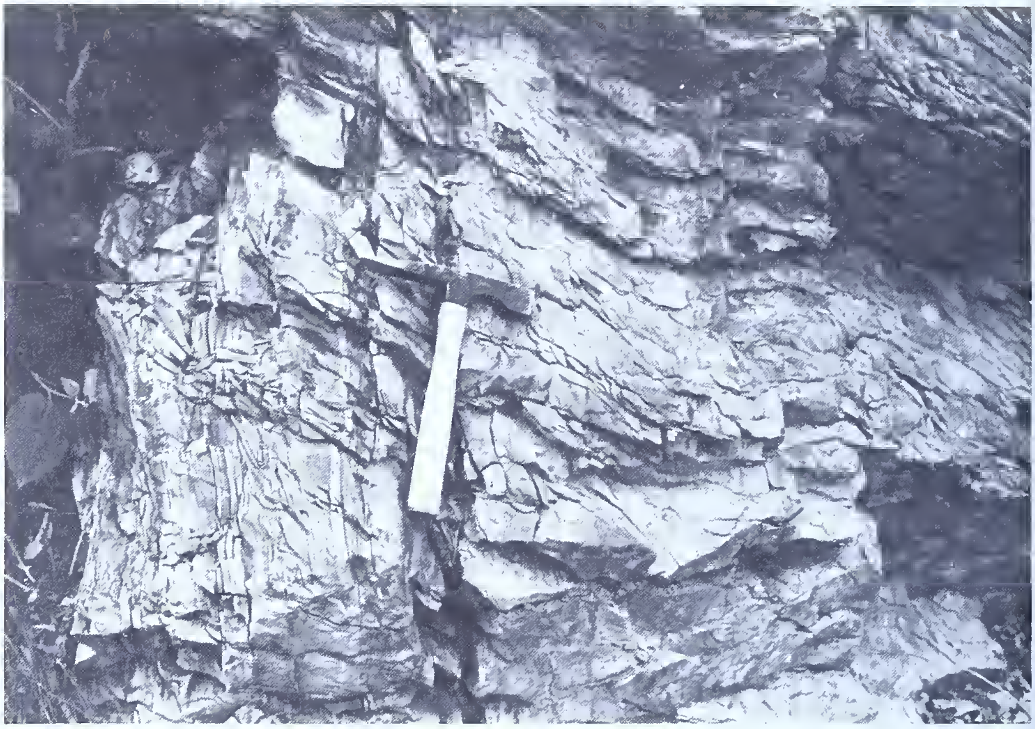


Figure 57. Laminated to thin-bedded and graded limestone of the basal part of the Bossardville Limestone (to left of hammer) resting on mud-cracked dolomite of the Poxono Island Formation. Exposure along Central Railroad of New Jersey. See units 12 and 13 of measured section 1 for details.

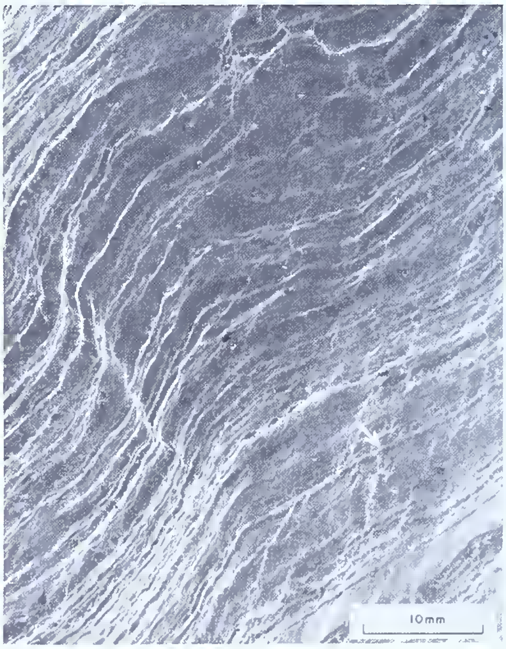


Figure 58. Laminated micrite and pelmicrite (dark) and calcareous shale (light) in mud-crack column, Bossardville Limestone, unit 3 of measured section 2. Laminations may be partly of organo-sedimentary (algal) origin. Stratigraphic top is up. Cleavage (arrow) offsets laminae. Negative print of acetate peel. Figure 61 is outcrop of rock.

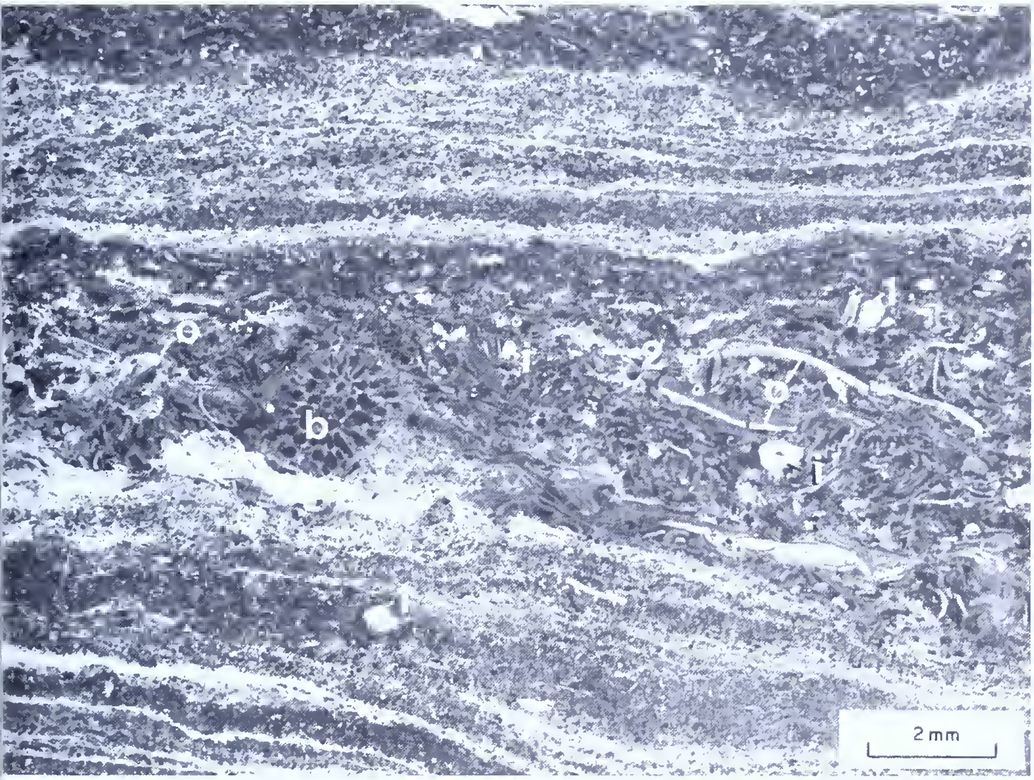


Figure 59. Laminated limestone (dark) and calcareous shale (light) in uppermost bed of Bossardville Limestone, unit 12 of measured section 2. Most laminae are graded. Coarsest lamina thickens to right and contains many ostracode fragments (o) and some bryozoans (b) and small micrite intraclasts (i), some of which are recrystallized to spar in the center. A few complete ostracode carapaces are filled with micrite (1) or spar (2). Angular silt- and very fine sand-sized quartz is scattered throughout. Stratigraphic top is up. Negative print of thin section.

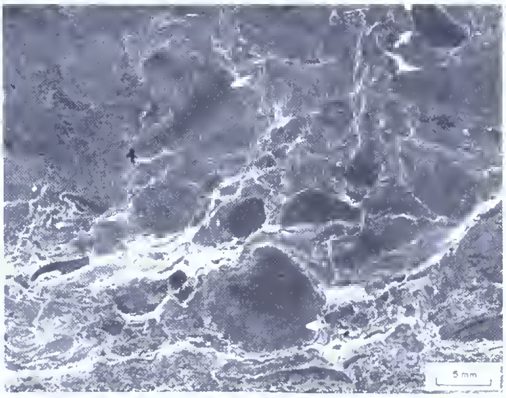


Figure 60. Micrite intraclasts (dark) rimmed by encrusting bryozoans (arrows) in irregularly bedded limestone in the Bossardville Limestone, unit 7 of measured section 2. Cleavage appears as irregular white lines. Stratigraphic top is up. Negative print of acetate peel.

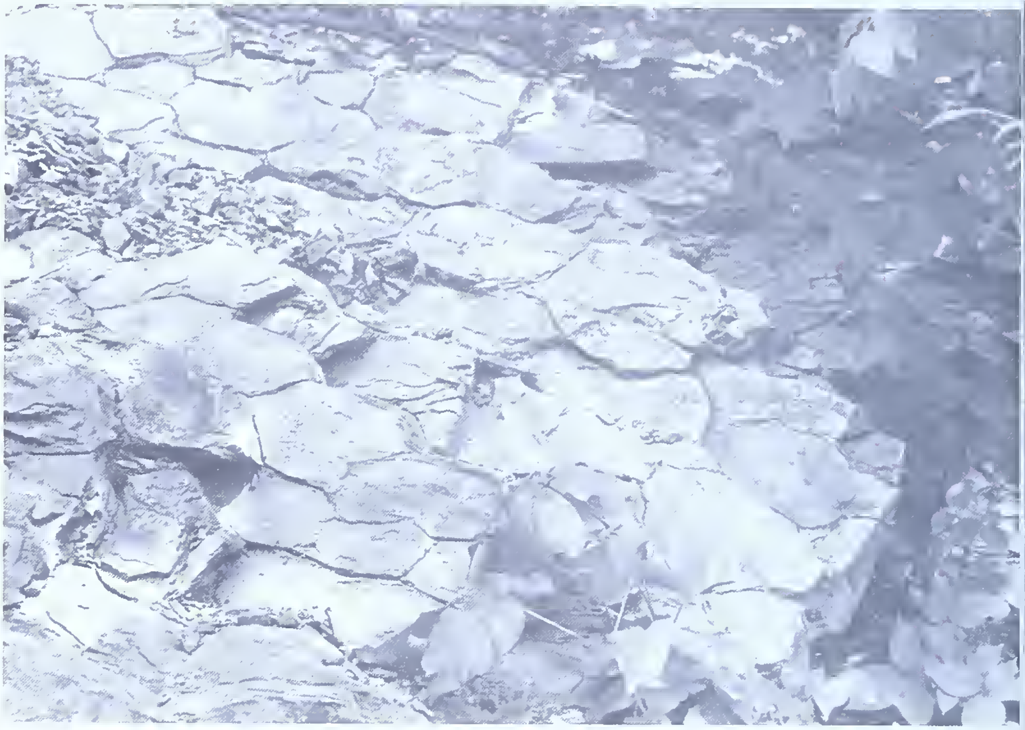
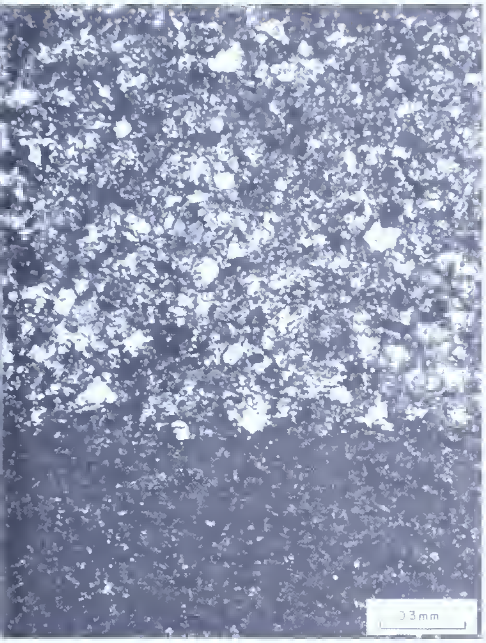


Figure 61. Mud cracks in Bossardville Limestone, unit 3 of measured section 2. The polygons are as much as 10 inches long and are tectonically elongated from left to right. Note shale fillings. Poison ivy in lower right gives scale. Figure 58 is print of peel of rock.

The shale in the Bossardville is greenish gray (5GY6/1) to light-olive gray (5Y6/1), weathers grayish orange (10YR7/4), and is calcareous and partly dolomitic. X-ray diffraction analyses of the shales, as well as the limestones, show that the clay minerals are muscovite, chlorite and montmorillonite (Figure 56B—see discussion under Poxono Island Formation).

In the Phillips Petroleum Company exploration well No. 1 Graver Estate (section 24), the Bossardville is between a depth of 5,170 and 5,255 feet and consists of very fine grained argillaceous and silty fossiliferous limestone with "pseudo-oolites" (probably bryozoan- or algal-encrusted intraclasts) and black silty and calcareous shale.

In thin section, the basal laminae of graded sequences are calcisiltites (Figures 62 and 63), biosparrudites, and biomicrudites (Figure 64), with abundant pellets and intraclasts in some rocks. Some laminae are very fossiliferous and contain abundant ostracodes (mostly fragmented) and some bryozoans. Sparse shell material made up of collophane was seen and may be fragments of *Lingula*. Quartz grains are scattered throughout all sections studied and increase in abundance upward as the overlying



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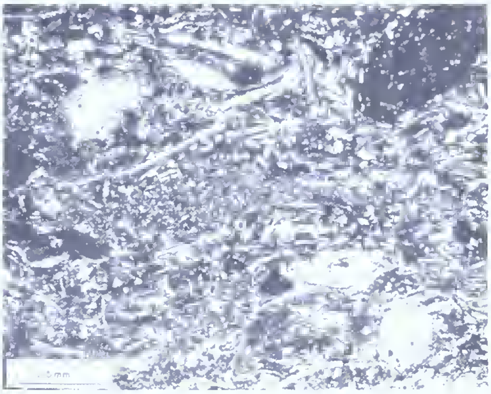

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Figure 62. Photomicrograph (crossed polarizers) of calcisiltite resting on micrite in Bossardville Limestone, unit 13 of measured section 1. The rock is part of a sequence of graded laminae of calcisiltites at the base (calcite grains are the same size as angular and etched quartz, suggesting that the calcite is clastic), grading up into silty biomicrite (see Figure 66) and partly pelletal micrite. The contact between the coarser basal laminae and micrite of the upper part of the underlying graded sequences is sharp, as shown here.

Figure 63. Photomicrograph (plane-polarized light) of ostracode calcisiltite in Bossardville Limestone. The rock is made up of angular quartz silt (q), abundant ostracode fragments and complete carapaces, and some silty micrite intraclasts (i). Note sparry calcite fillings (s) of the complete shells. Bedding is horizontal in photograph. Unit 5 of measured section 2.

Decker Formation is approached (Figure 65) and may make up 25 percent of the rock. The quartz ranges from silt to very fine grained sand. It is generally angular, although much of the quartz is etched and replaced by calcite so that the original shape cannot be determined. Plagioclase is present but rare. Grains of quartz, calcite, muscovite, and micrite fragments or intraclasts are commonly the same size in many laminae, suggesting that they are all detrital. Some intraclasts, however, are larger than the width of the thin section. Euhedral dolomite rhombs were seen in many sections.

The basal coarser laminae grade up into biomicrudite, biomicrite, and biopelmicrite (Figure 66). Many laminae have been disturbed by burrowing organisms. Shell material is less abundant and smaller than in

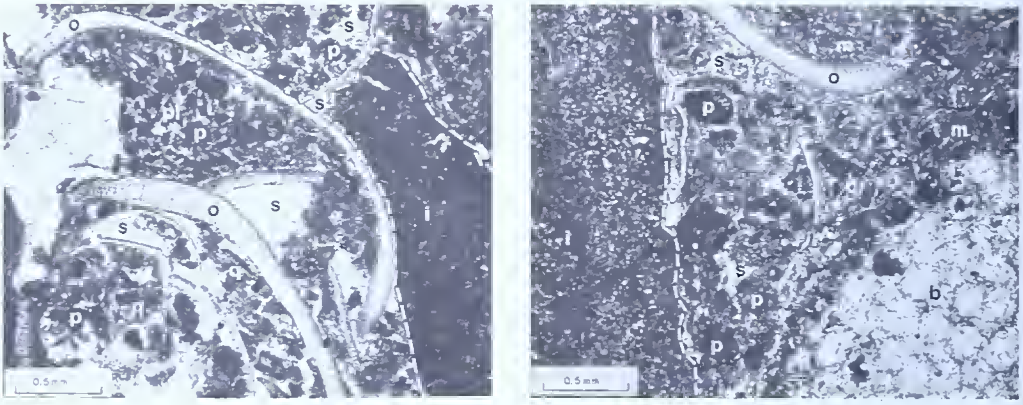


Figure 64. Photomicrographs (plane-polarized light) of intraclastic biopelsparrudite and probably neomorphosed biopelmicrudite in the Bossardville Limestone, unit 7 of measured section 2. Fossils are ostracodes (o) and bryozoans (b). Pellets (p) are abundant. Intraclasts (i, outlined) of laminated micrite and calcisiltite are common and are more than 7 mm long. Many intraclasts are surrounded by encrusting Bryozoa and possibly algae but are not seen in these photographs (see Figure 59). Note spar fillings of voids between shells, intraclasts, and pellets. Silt-sized quartz (q) and rare plagioclase (pl) are scattered throughout. Much of the finer groundmass is made up of equigranular microspar (m), so some of the rock may have been biopelmicrudite affected by aggrading neomorphism (see Folk, 1965).

underlying coarser laminae and is generally fragmental. Micrite intraclasts also occur.

The upper finest part of a graded sequence is pelletal micrite (Figure 62) to calcareous shale. The top is generally beveled by the overlying coarse bed. Some of the micrite may have been neomorphosed to microspar (Figure 64). The calcareous shale appears as concentrations of fine quartz and muscovite and rare plagioclase in a matrix of micrite. Some of the fine laminae are less than 0.04 mm thick and appear dark (carbonaceous film?) in plane-polarized light. These may be of organosedimentary (algal) origin.

The contact between the Bossardville Limestone and the overlying Decker Formation is placed at the base of the lowest calcareous siltstone or sandstone of the Decker. This boundary is transitional because some limestones that are found in the Decker are also typical of the Bossardville. Because the Decker is the youngest undisputed Silurian unit (for example, see Swartz and Swartz, 1941), the Bossardville is also Late Silurian in age.

The Bossardville Limestone has been quarried for agricultural lime in the past and is presently quarried at Bossardsville, Pennsylvania, for con-

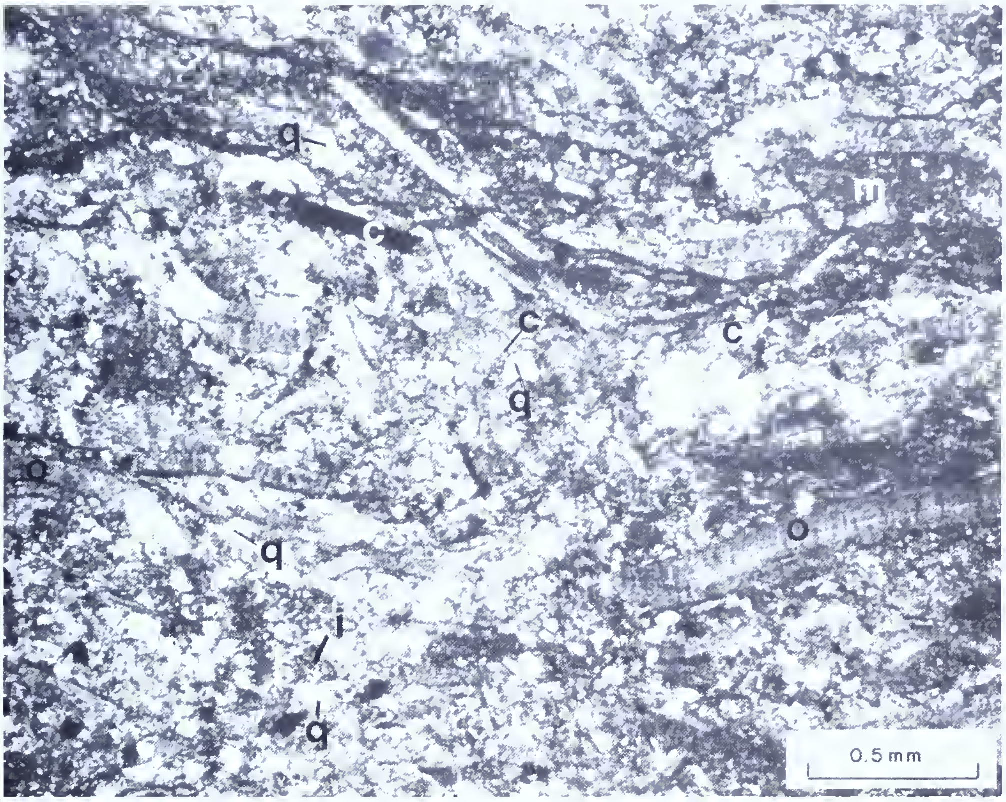


Figure 65. Photomicrograph (plane-polarized light) of fossiliferous quartzose calcisiltite in the Bossardville Limestone. Abundant ostracode fragments (o) and rare collophane (*Lingula?* fragment, c) are parallel to bedding. Angular to subangular quartz silt to very fine sand (q) and micrite intraclasts (i) make up about 25 percent of the rock. Some micrite (m) fills interstices. Calcite grains about the same size as the quartz, and apparently derived from fragmentation of shells, make up the remainder of the rock. This sample is from unit 12, the top bed in the Bossardville Limestone at measured section 2, and demonstrates the increasing quartz content as the overlying Decker Formation is approached.

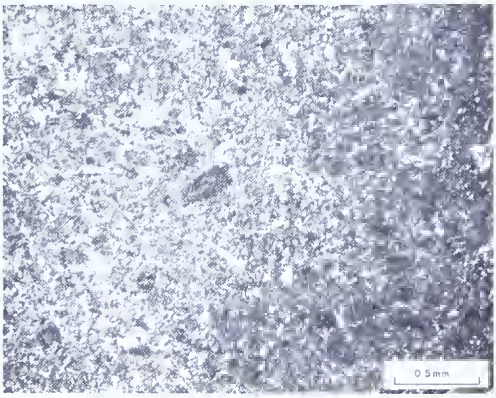


Figure 66. Photomicrograph (plane-polarized light) of biopelmicrite, typical of laminae sandwiched between coarser and finer grained rocks in graded sequences (see Figure 62), Bossardville Limestone. The fossil fragments are ostracodes. Bedding is vertical in the photograph. Unit 9 of measured section 2.

struction materials and limestone "sweetener" in cement. The calcium carbonate content probably varies between 60 percent in the more argillaceous beds to 95 percent in the purer beds (see chemical analysis 3 in Table 5).

## Decker Formation

Rocks herein assigned to the Decker Formation were originally called Decker's Ferry by White (1882) along the Delaware River and later included in the Keyser Group along with the overlying Rondout Formation and Manlius Limestone by Swartz (1929) and later workers. The tripartite division could not be recognized in the Lehigh River area, and these rocks were assigned to the Keyser Limestone by Swartz (1939) and Swartz and Swartz (1941). The confused history of nomenclature was reviewed by Epstein and others (1967) who defined the Decker Formation east of Bossardsville, Pennsylvania (20 miles northeast of the Lehigh River), as consisting of two members: a limestone facies northeast of the Wallpack Center area, New Jersey (Clove Brook Member), and a sandier facies to the southwest (Wallpack Center Member). Exposures of the Decker Formation are scanty between Bossardsville and the Lehighton and Palmerton quadrangles, but it appears that most of the rocks are characteristic of the Wallpack Center Member, although a few feet of fossiliferous limestone at the base of the formation exposed only near Palmerton is similar to rocks in the Clove Brook Member. Because of the poor exposures and uncertainty of lateral continuity, the rock unit in the report area is referred to as the Decker Formation.

In the Lehighton and Palmerton quadrangles, the Decker Formation is exposed at only three localities: in an abandoned quarry 1,500 feet northeast of the Hazard School in Palmerton, where 26 feet of rock was measured (measured section 2); in a parking lot 5,500 feet east of Ashfield, where an incomplete thickness of 55 feet was measured (measured section 3); and in a 15-foot-long exposure in a dirt road in Aquashicola. Elsewhere, the Decker may be traced by float of siltstone, sandstone, and some red beds along the south slope of Stone, Stony, and Chestnut Ridges, but for the most part, even the float is covered by colluvium from rock units above.

Limestone is abundant in the lower 5 feet of the Decker and is overlain by about 70 feet of calcareous siltstone and sandstone. These rocks are succeeded by about 20 feet of red beds (the Andreas Red Beds of Swartz and Swartz, 1941) that may be of Decker age or younger.

The limestone is generally silty to finely arenaceous and very fine to fine grained, but some beds are medium to coarse grained and contain medium-grained quartz sand (Figure 67). Colors of fresh rocks are

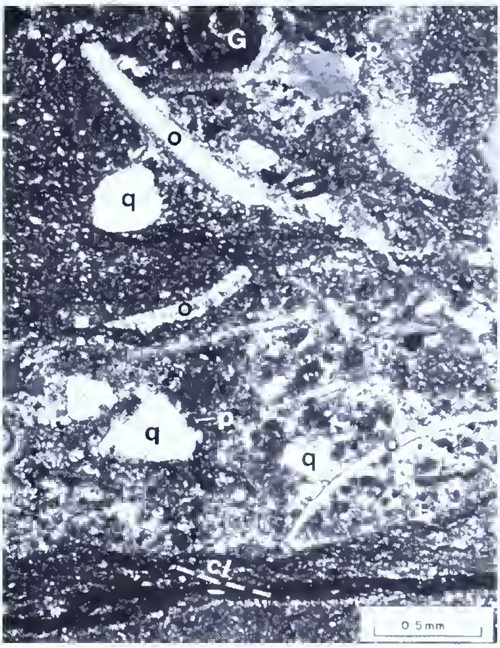


Figure 67. Photomicrograph (crossed polarizers) of pelletal sandy biosparrudite, Decker Formation, unit 17 of measured section 2. The rock consists of ostracode fragments (o), rare gastropods (G), subrounded to subangular quartz grains (q) nearly 8 mm long, and some pellets (p) in a sparry calcite matrix. The limestone rests sharply on a calcareous shale in which cleavage (cl) is prominent.

medium-dark gray (N4) to medium-light gray (N6). They are partly leached in outcrop and weather to yellowish brown (10YR5/4), medium gray (N5) to medium-light gray (N6), and light-bluish gray (5B7/1). The limestones are irregularly laminated to micro cross laminated. Some beds are as much as 0.75 inch thick. Graded beds and laminae are common (Figure 68). In general, coarse-grained quartzose limestone containing shell hash (Figure 69) and limestone intraclasts as much as 5 inches long at the base has an abrupt lower contact with (Figure 67) and grades up into calcareous shale or shaly very fine grained limestone containing scattered fossils. Fossils in the limestones include abundant whole carapaces and fragments of ostracodes, some brachiopods, bryozoans, stromatolite hemispheroids of low relief (as much as 8 inches in diameter) and crinkly laminated beds believed to be stromatolites, and rare acodid conodonts (Figures 67-70).

The limestones are generally poorly sorted biomicrudites near the base (Figure 69) and become richer in quartz and lose much of the micrite matrix (indicating greater current activity resulting in winnowing) higher up, as shown by the sandy biosparrudite in Figure 67. Also indicative of stronger current action are oosparites (Figure 70). The oolites

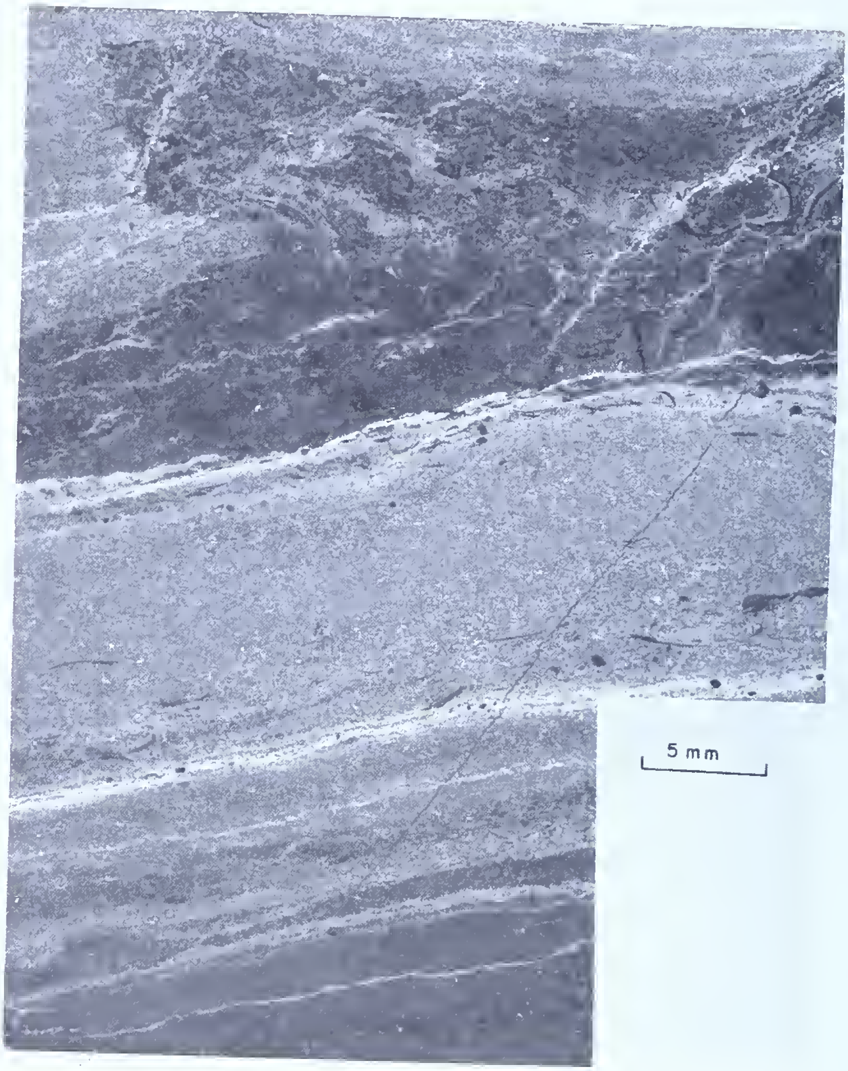


Figure 68. Laminated fossiliferous limestone (dark) and calcareous silty shale (light), Decker Formation, unit 17 of measured section 2. The shale is graded; ostracode fragments are more abundant at the base of a graded unit. The limestone contains ostracodes, bryozoans, and rare gastropods (biosparrudite), as well as scattered medium-grained quartz sand. Bedding is partly disrupted and limestone intraclasts as much as 5 inches long are found in surrounding beds. Negative print of acetate peel. Figure 67 is a photomicrograph of a limestone lamina.

and related fossil fragments and intraclasts are well sorted and cemented with sparry calcite. Very little micrite is present, attesting to vigorous winnowing.

Interbedded with the limestones are calcareous and partly arenaceous platy to massive and laminated greenish-gray (5GY6/1) siltstone and medium-dark-gray (N4) to medium-light-gray (N6) silty shale in laminae and beds less than 0.25 to as much as 3 inches thick. These fine terri-

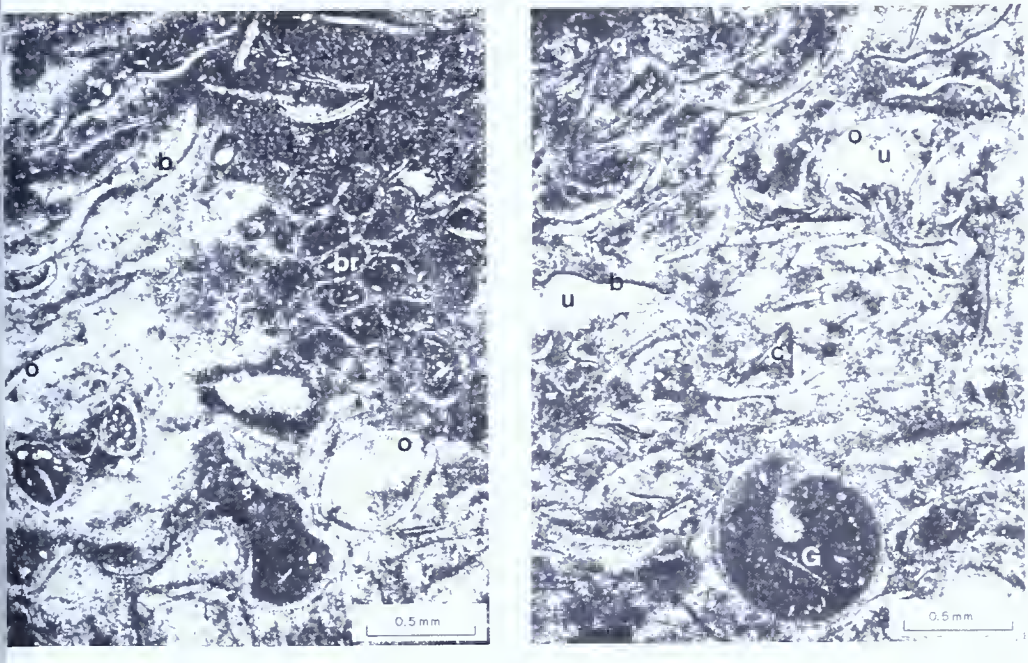


Figure 69. Photomicrographs (plane-polarized light) of biomicrudite, Decker Formation, unit 15 of measured section 2, about 2 feet above base of formation. Ostracode (o) fragments and whole shells are abundant, brachiopod (b) fragments, Bryozoa (br), and gastropods (G) are less common, and conodonts (c, an acodid element) are rare. Carapaces are filled with light sparry calcite or dark micrite. Umbrellas (u), where the pore space in the convex-upwards shell is filled with sparry calcite, are common. Quartz silt is rare.

genous clastic materials are leached and weathered to grayish orange (10YR7/4) to dark-yellowish orange (10YR6/6) and moderate brown (5YR3/4 to 5YR4/4).

Terrigenous clastic rocks increase in abundance above the basal limestone in the lower 7 feet of the Decker Formation and are predominantly siltstones and very fine grained sandstones, although some of the sandstones are coarser grained. The sandstones are partly laminated and platy (Figure 71) to massive. Beds are as much as 3.5 feet thick. Small-scale cut-and-fill structures are numerous. Many rocks are burrowed, apparently more extensively near the base of the Decker (Figure 72) than in immediately overlying beds (Figure 73). Fossils found are favositid corals, ostracodes (including kloedenid ostracodes), crinoid columnals, and brachiopods (including abundant *Eccentricosta jerseyensis* that give these rocks a straticulate appearance). All of the sandstones and siltstones are leached in outcrops, are limonitic, and generally weather to pale-yellowish orange (10YR8/6) to dark-yellowish orange (10YR6/6), light brown (5YR6/4) and moderate-reddish orange (10R6/6) to grayish red (10R4/2).

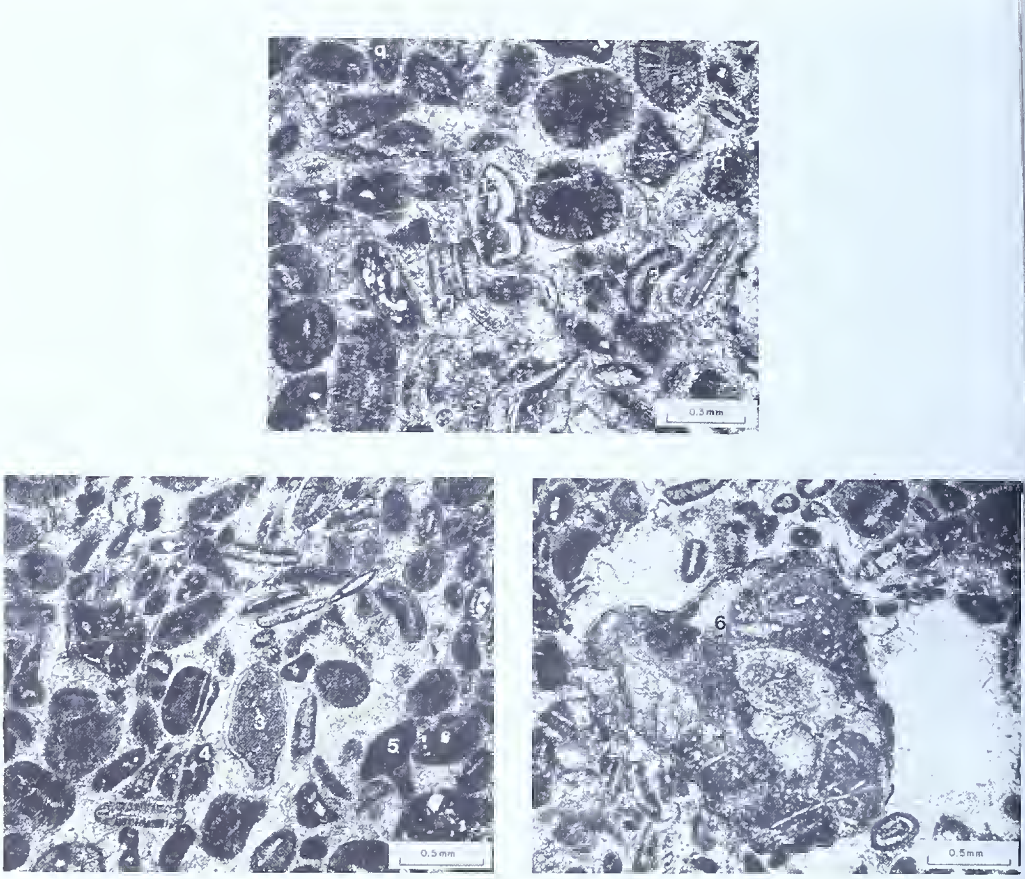


Figure 70. Photomicrographs (plane-polarized light) of oosparite in Decker Formation, about 2.5 feet above base, unit 15 of measured section 2. The well-sorted oolites have both radial and concentric structure. Nuclei in the oolites include brachiopod (1) and ostracode fragments (2), as well as quartz grains. Micrite-filled ostracode carapaces (3) and intraclasts of pelsparite (4) and micrite (5) are generally about the same size as the oolites (averaging about 0.5 mm), although some intraclasts of silty biomicrudite (6) are as much as 2 mm long. Scattered angular quartz grains (q) do not exceed 0.4 mm in length.

In the water well drilled for New Jersey Zinc Company at Palmerton (measured section 4), the lowest beds of the Decker Formation are pebbly. Five feet of light- to medium-brown coarse conglomeratic sandstone was penetrated below 36 feet of sand and gravel in the U.S. Army Corps of Engineers drill hole, 400 feet north of the road at Walkton. In the Phillips Petroleum Company exploration well No. 1 Graver Estate (measured section 24), the Decker Formation is interpreted to have been penetrated between 4,960 and 5,160 feet. The rocks consist of fossiliferous conglomerate, partly conglomeratic sandstone, and fine-grained sandy limestone. Some of the younger beds in this sequence may be part of the overlying Coeymans Formation, but pseudo-oolites (probably oncolites)

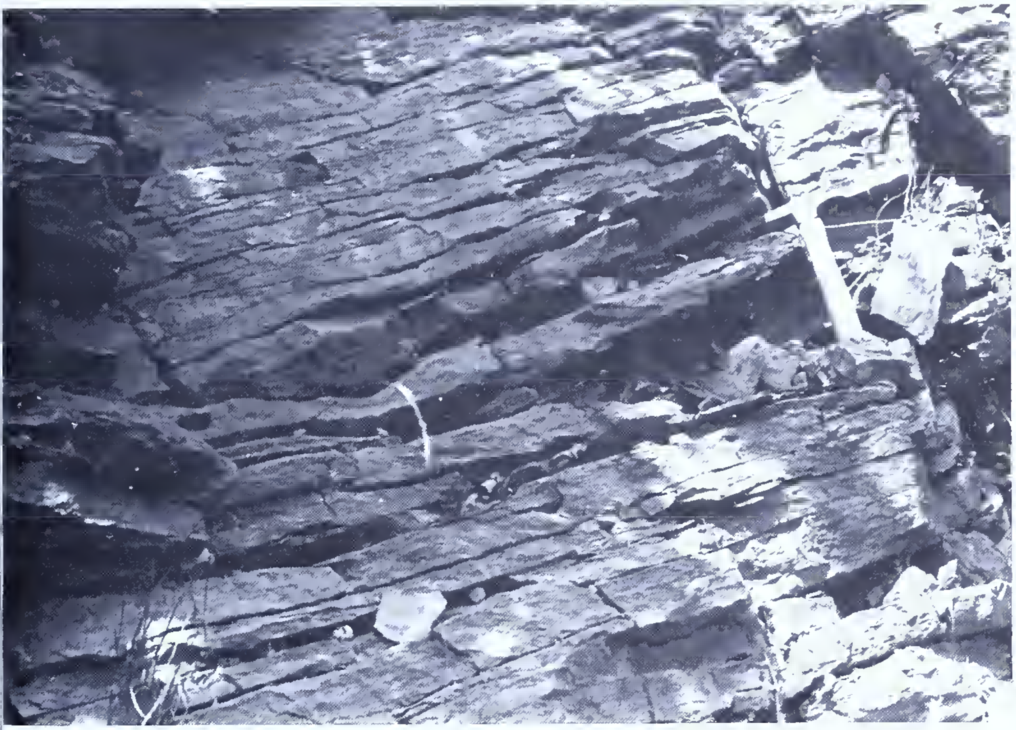


Figure 71. Platy wavy-bedded and laminated fossiliferous partly burrowed siltstone, shale, and sandstone in the Decker Formation, unit 20 of measured section 2. Hammer gives scale. Figure 73 is a close-up of the rock, and Figure 74 is a photomicrograph.

in unit 12 of measured section 24 and microfossils (probably leperditiid ostracodes) in unit 11 are known from the Decker in the outcrop belt, not from the Coeymans. Samples between 4,960 and 4,965 feet (coarse sandstone and argillaceous limestone) and between 4,980 and 4,985 feet (argillaceous coarse-grained limestone) were examined for microfossils in order to establish the age of these rocks. Unfortunately, only a few undiagnostic brachiopod fragments were found.

The sandstones are graywackes. They have a content of matrix minerals including muscovite, quartz, and chlorite, as well as limonite and some calcite. Some contain plagioclase and may also grade into sandy shaly siltstone (Figure 74).

The quartz in the sandstones is rounded to angular; larger grains are more rounded. Most quartz occurs as single grains having undulose extinction, although a few grains have straight extinction. There are some polycrystalline grains. The quartz may have a limonite "clay" coating or is in penetration contact with other grains. Quartz overgrowths are common. Some grains have vermicular chlorite inclusions altered to limonite. Many quartz grains are corroded along their edges and are replaced by muscovite. Silt- and sand-sized muscovite is abundant. Sub-

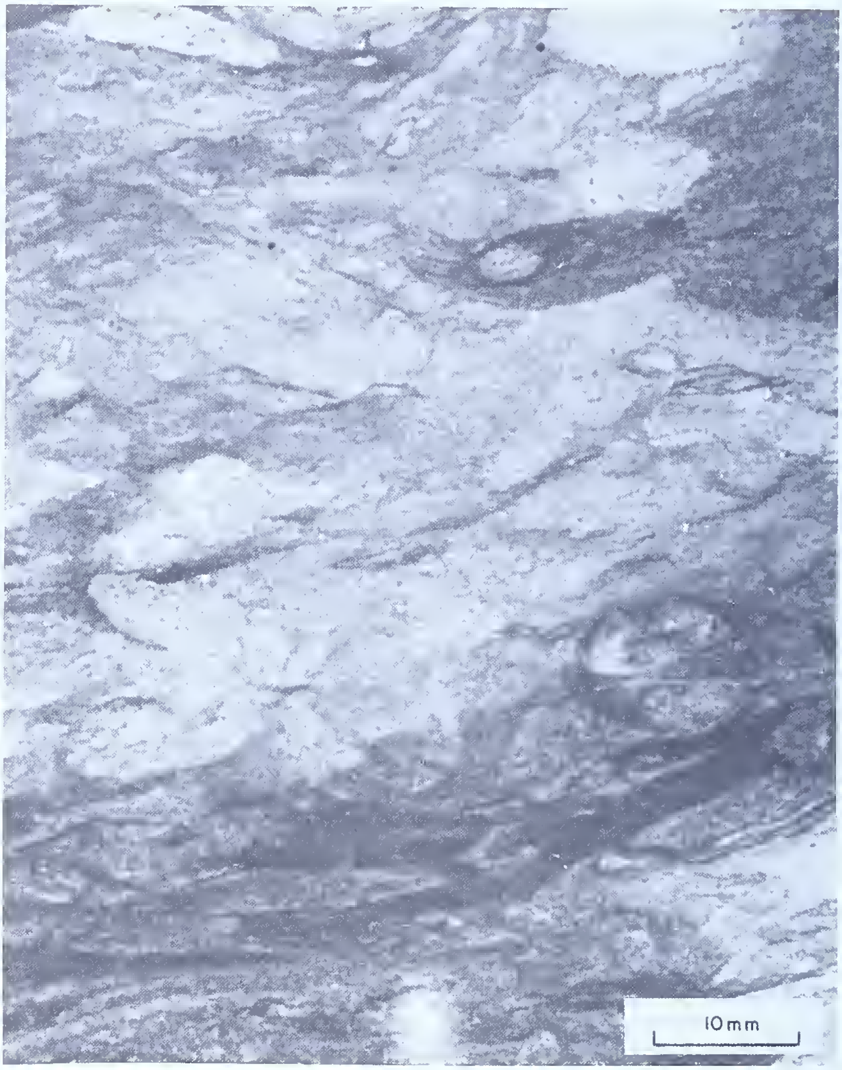


Figure 72. Extensively burrowed calcareous siltstone to very fine grained sandstone, Decker Formation, about 13 feet above the base, unit 19 of measured section 2.

angular to rounded chert makes up less than 1 percent of all rocks examined. Plagioclase is even less abundant. Small amounts of limonitic brownish mica may be weathered biotite. Minor rock fragments include shale and micaceous sandstone. Other minerals include subordinate subhedral to rounded tourmaline, zircon, and lesser rutile, as well as variable amounts of leucoxene. The matrix minerals, in decreasing order of abundance, are muscovite, quartz, and chlorite, with variable calcite (absent in thoroughly leached rocks), limonite, and hematite.

Chemical analyses of a dolomitic shaly limestone and calcareous silty sandstone are given in Table 5. X-ray diffraction analyses show that all limestones and calcareous shales and siltstones contain calcite, muscovite,

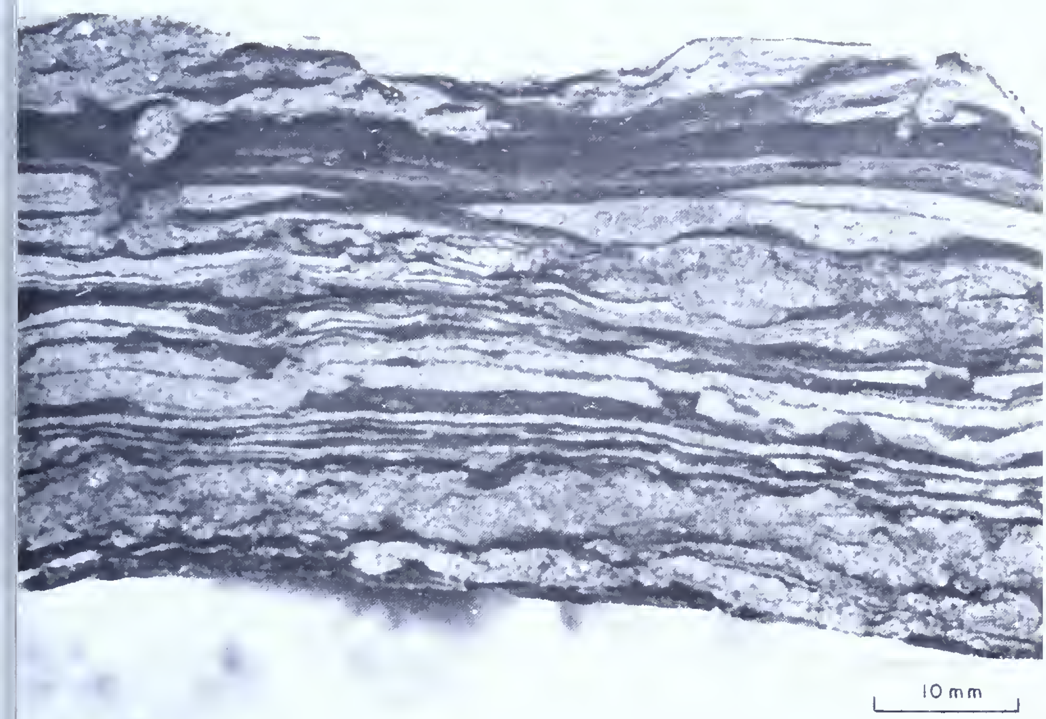


Figure 73. Unevenly laminated and partly burrowed calcareous shale, siltstone, and fine-grained sandstone in the Decker Formation, about 25 feet above the base, unit 20 of measured section 2. Figure 74 is a photomicrograph of the rock.

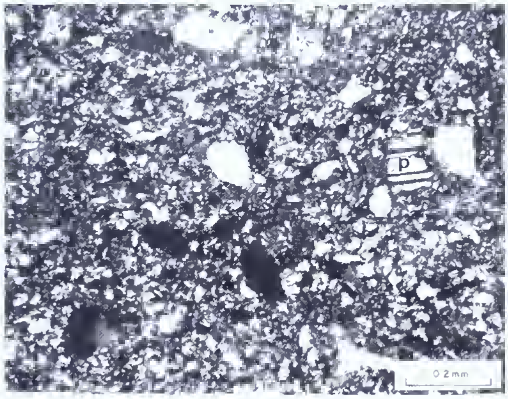


Figure 74. Photomicrograph of laminated and partly burrow mottled shaly siltstone to micaceous fine-grained graywacke, Decker Formation, unit 20 of measured section 2. The coarser grains are quartz and minor plagioclase (p). These float in a finer muscovite, quartz, and chlorite matrix. Figure 73 shows the rock.

quartz, and lesser chlorite, and mixed-layer illite-montmorillonite (Figure 56, sample D). Some laminae contain nearly as much dolomite as calcite (Figure 56, sample C), but these are not common. The weathered sandstones and siltstones of measured section 3 contain quartz, muscovite, some feldspar, degraded chlorite, and kaolinite. Degradation of the chlorite and formation of kaolinite are due to weathering. Pyrophyllite was found in the Decker and other formations in samples from the Phillips Petroleum exploration well No. 1 Graver Estate (measured section 24).

The occurrence of pyrophyllite is of interest because it indicates that the rock in which it is found may have undergone low-grade metamorphism (for example, see Hosterman and others, 1970).

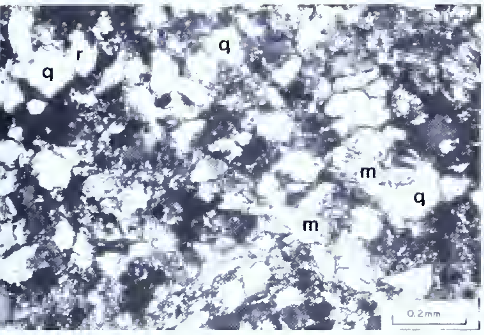
Overlying the sandstones and siltstones just described, and herein tentatively included in the Decker Formation, is a thin sequence containing red beds that Swartz and Swartz (1941) named the Andreas Red Beds. At the type locality, in the quarry of William Loch, 0.5 mile southeast of Andreas, Pennsylvania, about 2 miles west of the southwest corner of the Lehighton quadrangle, the Andreas Red Beds are 17.5 feet thick; the base is concealed (Swartz and Swartz, 1941).

The Andreas Red Beds east of Andreas are only exposed about 1 mile east of Ashfield (measured section 3), where the unit is 21 feet thick. It can be traced eastward in float only to the center of Palmerton, but float mapping is difficult because of colluvial cover. The red beds were not found in the Phillips Petroleum Company exploration well No. 1 Graver Estate, 4 miles north of Palmerton.

The Andreas at section 3 consists of very fine to very coarse grained and conglomeratic sandstone (pebbles are as much as 5/8 inch long), shale, and siltstone. Some beds are burrowed. The red beds are hematitic, some are oolitic (ooids average about 0.3 mm in diameter), and are pale red (5R6/2 to 10R6/2), grayish red (5R4/2), and moderate red (5R4/4). Nonred beds weather moderate brown (5YR4/4) to grayish orange (10YR7/4) and pale-reddish brown (10R5/4). The sandstones are apparently mostly lithic graywackes (Figure 75), although some of the coarser rocks are orthoquartzites (Figure 76).

The Decker Formation, at least those beds below the Andreas Red Beds, is Silurian in age; it contains the diagnostic fossil *Eccentricosta jerseyensis*. The fauna is discussed more fully by Swartz (1939) and Swartz and Swartz (1941).

No fossils have been found in the Andreas Red Beds. The unit may be of Decker ("Keyser") or Stormville (Coeymans) age; that is, latest Silurian or Early Devonian (Swartz and Swartz, 1941; Epstein and Epstein, 1969), or it may be separated from rocks above and below by unconformities and be correlative to rocks present to the east in the Delaware



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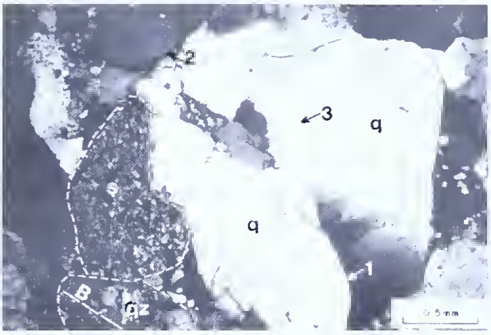

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Figure 75. Photomicrograph (crossed polarizers) of very fine grained hematitic lithic graywacke, Decker Formation (possibly basal bed of the Andreas Red Beds of Swartz and Swartz, 1941), unit 11 of measured section 3. Quartz (q, 54 percent) is angular and mostly single grain with strongly undulose extinction, although there are some polycrystalline grains; many quartz grains have rutile inclusions, and most have corroded edges and are replaced principally by muscovite. Muscovite (m) grains are about the same size as the quartz grains and, with rock fragments of micaceous sandstone and shale (r), make up about 10 percent of the rock. Minor mica is limonitic and appears to be weathered biotite. Chert is not common. Rounded zircon and green angular to rounded tourmaline form less than 0.5 percent of the rock. The matrix (36 percent) is mostly made up of limonite and hematite "clay," muscovite, and lesser quartz.

Figure 76. Photomicrograph (crossed polarizers) of very coarse grained orthoquartzite, Andreas Red Beds of Swartz and Swartz (1941) of the Decker Formation, unit 13 of measured section 3. The rock is made up of more than 95 percent quartz (q) and quartzite (qz) grains. Note bedding (B) in laminated quartzite grain. Most quartz occurs as single grains with undulose extinction or as polycrystalline vein quartz. Some contain vermicular chlorite altered to limonite. The grains are well rounded to subrounded. Grains have penetration contacts (at 1) or are rimmed with hematite and limonite (at 2). A few have quartz overgrowths (at 3). Rock fragments, mostly micaceous and siliceous siltstone (s), are rare.

Water Gap area, such as the Rondout Formation or the lower part of the Coeymans Formation.

The lowest beds in measured section 3 may be near or stratigraphically above the sequence exposed at measured section 2. Therefore, the Decker is at least 80 feet thick, including the Andreas Red Beds. Swartz and Swartz (1941) measured 93 feet of Decker (their "Keyser"), although they described 39 feet of fossiliferous "impure lumpy limestone" at the base, some of which might be placed in the underlying Bossardville Limestone, as defined in this report. At Andreas, in the quarry of William Loch, Swartz and Swartz (1941) reported a thickness of 90 feet of their Keyser Formation, including the Andreas Red Beds, but some of the basal beds might be placed in the Bossardville (note that their total thickness of 81 feet is incorrect because of faulty addition). Thus, the total thickness of the Decker Formation, including the Andreas Red Beds of Swartz and Swartz, is between 80 and 90 feet.

The contact between the Decker Formation and underlying Bossardville Limestone is placed at the base of the lowest calcareous siltstone of the Decker. This contact is exposed only at measured section 2. The upper contact of the Decker, exposed only at section 3, is placed at the top of the highest red bed of the Andreas Red Beds. The Decker is overlain by rocks believed to be the Stormville Member of the Coeymans Formation (see below). The Rondout Formation and lower part of the Coeymans Formation, recognized above the Decker east of the report area, are not present in the Lehighton and Palmerton quadrangle (see Epstein and Epstein, 1969, Figure 6) .

Because the Decker cannot be readily distinguished from the overlying Stormville, the two units have been mapped together.

## LOWER DEVONIAN

### Stormville Member of the Coeymans Formation

The Coeymans Formation of the Helderberg Group was named by Clarke and Schuchert (1899) for strata between the Manlius and New Scotland Limestones at Coeymans, New York. White (1882) included strata in eastern Pennsylvania in his Stormville Conglomerate and Stormville Limestone which were later correlated with the Coeymans by Grabau (1906). Epstein and others (1967) redefined the Coeymans Formation in eastern Pennsylvania, New Jersey, and southeasternmost New York. In the Stroudsburg-Bossardsville area, about 15 miles northeast of the Palmerton quadrangle, four members were recognized. These are, in ascending order, the Depue Limestone (limestone), Peters Valley (arenaceous limestone and calcareous conglomeratic sandstone), Shawnee Island (limestone), and Stormville (calcareous conglomeratic sandstone and arenaceous limestone). The Coeymans becomes increasingly arenaceous and conglomeratic southwest of the New York border (Epstein and others, 1967) , so that the Stormville is the only member of the Coeymans Formation present near Kunkletown, about 6 miles east of the Palmerton quadrangle (Epstein and Epstein, 1969) . Swartz (1939, Figure 17) similarly showed the lateral change of all other members of the Coeymans into what is herein called the Stormville in the Palmerton area. From the single exposure of these rocks at measured section 3, it appears that the Stormville continues into the Lehighton and Palmerton quadrangles.

In the Kunkletown area, the Stormville contains *Gypidula coeymanensis,* a brachiopod characteristic of the Coeymans. Unfortunately, the rocks are deeply weathered at their only exposure in the report area, and no fossils were found. Also, the Andreas Red Beds, a useful marker horizon below the Stormville in the Lehighton quadrangle, do not extend to the Kunkletown area. Therefore, the identification of the Stormville in the Lehighton and Palmerton quadrangles is open to some question, but the stratigraphic position of these rocks strongly suggests its correlation.

The reference section for the Stormville Member of the Coeymans Formation is at Hartmans Cave, 2.5 miles southwest of Stroudsburg, Pennsylvania, and 22 miles northeast of Palmerton (Epstein and others, 1967). At this locality, the Stormville is 25 feet thick and consists of medium-gray to medium-light-gray, fine- to coarse-grained, conglomeratic, calcareous, planar-bedded and crossbedded, lenticular, partly limonitic sandstone, quartz-pebble conglomerate with rounded pebbles as much as 1 inch long, and fine- to coarse-grained arenaceous limestone. The unit is fossiliferous, containing scattered rugose corals, stromatoporoids, crinoid columnals, and *Gypidula coeymanensis.* The rocks weather light-olive gray to medium-light gray.

In the Lehighton quadrangle (measured section 3), the Stormville consists of deeply weathered very fine to very coarse grained sandstone and minor shale and siltstone. Some of the sandstone is conglomeratic, containing rounded and subrounded quartz pebbles as much as ½ inch long. Most of the rocks are porous, presumably because of leaching of calcium carbonate. Most sedimentary features have been obliterated by weathering. Weathering colors are generally light brown (5YR5/6) to grayish orange (10YR7/4) and dark-yellowish orange (10YR6/6), moderate-orange pink (5YR8/4) to moderate-reddish orange (10R6/6), and grayish red (5R4/2).

The sandstones in the Stormville appear to be better sorted than those in the underlying Decker Formation. Protoquartzites are most common (Figure 77), but some of the rocks may be orthoquartzites.

X-ray analyses of the rocks in the Stormville show them to be made up of quartz, muscovite, and kaolinite (see sample E, Figure 56). The kaolinite is undoubtedly a weathering product. Minor feldspar was found in a few samples. Chlorite is absent to minor and degraded.

The lower 31.5 feet of the Stormville is exposed at measured section 3. Swartz and Swartz (1941) measured 52 feet of sandstone and clay in the Kline tunnel at Hazard. They tentatively referred these beds to the Coeymans Formation on the basis of stratigraphic position because no fossils were found.

In the Phillips Petroleum Company exploration well No. 1 Graver Estate (measured section 24), rocks believed to be the Coeymans Formation were found between 4,813 and 4,960 feet. These consist of fossiliferous (brachiopods, crinoid columnals), cherty, siliceous, argillaceous, dark-gray to grayish-black limestone and interbedded black shale. These

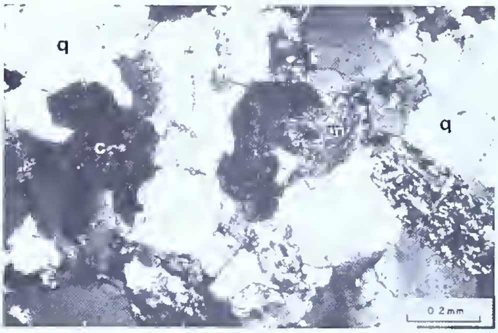


Figure 77. Photomicrograph (crossed polarizers) of medium-grained protoquartzite in the Stormville Member of the Coeymans Formation, unit 19 of measured section 3. The rock is made up predominantly of subangular to subrounded quartz (q, 84 percent) in a matrix (10 percent) of finer quartz, muscovite, altered chlorite, and limonite. Chert (c), siltstone (s), quartzite fragments, muscovite (m), and rare tourmaline and zircon form the remainder of the rock.

are not sandy as in the outcrop, representing a seaward decrease in terrigenous sediment.

## New Scotland Formation

The New Scotland Formation is not exposed in the Lehighton and Palmerton quadrangles. On the geologic map (Plate 1) it is combined with the Shriver Chert, to which it is somewhat lithically similar, and the Ridgeley Formation. The combined thickness of the New Scotland and Shriver Chert is 41 feet in the now-abandoned Klines tunnel at Hazard, Pennsylvania, according to Swartz and Swartz (1941) who termed the interbedded white chert and reddish and yellow clay the New Scotland Chert. In order to understand the nomenclature of these rocks, it is necessary to describe the stratigraphy between the Lehigh River and Delaware River to the east.

The name New Scotland was proposed in eastern New York by Clarke and Schuchert (1899). Equivalent beds in eastern Pennsylvania are the lower part of White's (1882) Stormville Shales, the New Scotland Shale of Willard (1938), New Scotland Shale and Limestone of Swartz (1939), and New Scotland Chert or Formation of Swartz and Swartz (1941). The New Scotland was established as a formation and was divided into two members in easternmost Pennsylvania and New Jersey by Epstein and others (1967)—the Flatbrookville below and Maskenozha above—following the earlier recognition of its twofold nature by Swartz (1939) and Swartz and Swartz (1941).

The New Scotland and overlying units are well exposed in roadcuts along U.S. Interstate 80 through Godfrey Ridge, 2.5 miles east of Stroudsburg, Pennsylvania. The New Scotland there is about 75 feet thick and consists of dark-gray to medium-dark-gray silty calcareous fossiliferous shale containing beds and lenses of medium-gray fine-grained argillaceous fossiliferous limestone and dark-gray chert. Overlying the New Scotland, in ascending order, are the Minisink Limestone (14 feet thick; argillaceous fossiliferous limestone), the Port Ewen Shale (151 feet thick; calcareous fossiliferous siltstone and shale), and the Oriskany Group, made up of the Shriver Chert below (85 feet thick; siliceous calcareous shale and siltstone, chert, and minor sandstone) and the Ridgeley Sandstone above (16 feet thick; coarse-grained fossiliferous sandstone, quartz-pebble conglomerate, and minor siltstone, arenaceous limestone, and chert). Details of the lithology of these rocks are given by Epstein and others (1967), Epstein and Epstein (1967, 1969), and Epstein (1971, 1973).

Southwest of Bossardsville, Pennsylvania, which is about 20 miles northeast of Palmerton, the New Scotland-Shriver interval is deeply weathered and poorly exposed. The best exposure in this area is near Kunkletown, Pennsylvania, in the clay pits of the Universal Atlas Cement Company, 4.7 miles east of the Palmerton quadrangle. At this locality the New Scotland, Shriver, and Ridgeley are exposed; the Minisink Limestone and Port Ewen Shale are not represented (Epstein and Epstein, 1969, Figure 53). The New Scotland is 55 feet thick and consists of fossiliferous weathered (white to light-gray and pale-yellowish-orange to light-brown) clay, chert, and silty to arenaceous clay. Near the top are lenses and thin beds of coarse-grained sandstone where the New Scotland grades into the overlying Shriver. The lower contact is sharp where cherty clay of the New Scotland rests on quartz-pebble conglomerate of the Stormville Member of the Coeymans Formation.

Fossils from the lower 16 feet of the New Scotland were identified by J. M. Berdan and J. T. Dutro, Jr. (written commun., 1968) and include the brachiopods *Meristella* sp., *Leptaena "rhomboidalis"* (Wilckens), and *"Schellwienella"* sp. cf. *"S." woolworthana* (Hall). These are consistent with a New Scotland age (in the New York type area), but all have also been reported from younger beds.

A more direct correlation may be made between the New Scotland Formation at the clay pits and the New Scotland in Godfrey Ridge. Approximately 400 silicified ostracodes were recovered from the lower 16 feet of the New Scotland at the clay pits. About 100 specimens were identifiable to a generic or specific level. These were identified by A. G. Epstein (written commun., 1971); her report is as follows:

> Ostracodes present in the collection are:
> - *Bollia* sp.
> - *Eucraterellina oblonga* (Ulrich and Bassler)
> - *E. randolphi* Wilson [=?*Thlipsura robusta* of Swartz, 1932]

*Reticestus? retiferus* (Roth)
*Thlipsurella?* aff. *T. fossata (Roth)*
*T. ellipsoclefta* Swartz

All these species were also found in collections of well-preserved silicified ostracodes from the New Scotland Formation in Godfrey Ridge. Collections of very well preserved pyritized ostracodes from the upper 20 feet of the Port Ewen Shale in Godfrey Ridge contain *Eucraterellina randolphi* Wilson and *E. oblonga* (Ulrich and Bassler) but lack all other species so far identified from the Chestnut Ridge collection. Port Ewen collections from Godfrey Ridge have abundant *Huntonella bransoni* Lundin, *Poloniella* sp., and *Thlipsura* aff. *T. furca* Roth. These species were not found in the New Scotland in Godfrey Ridge or in the clay pits near Kunkletown.

Bollias are very abundant in New Scotland collections in Godfrey Ridge but have not been identified in uppermost Port Ewen collections in the same area. Approximately 10 specimens of *Bollia* sp. were found in the clay.

The lower 16 feet of cherty white clay immediately overlying the Stormville Member of the Coeymans Formation in the clay pits is therefore probably correlative with part of the New Scotland Formation in Godfrey Ridge because: (1) All ostracodes identifiable to species from the clay also are found in the New Scotland Formation in Godfrey Ridge, whereas only two of these species have been found in large well-preserved collections from the upper Port Ewen; and (2) representatives of some species known to be abundant in the Port Ewen in Godfrey Ridge are absent in the clay.

Thus, on paleontologic and lithologic evidence, the New Scotland Formation extends from Godfrey Ridge to the Kunkletown area and presumably into the Lehighton and Palmerton quadrangles. The Minisink Limestone and Port Ewen Shale, which lack chert, are not present at Kunkletown. Whether they have been removed by erosion or were never deposited is difficult to say. Probably their absence is due to facies changes (the entire sequence becomes more cherty and sandier to the west) and to thinning by a multitude of diastems (the bases of the thin sandstones at the top of the New Scotland and in the overlying Shriver are minor unconformities). This interpretation is also supported by a fossil collection from the top of the New Scotland that is gradational into the Shriver at the clay pits. The fossils were identified by J. M. Berdan and J. T. Dutro, Jr., of the U.S. Geological Survey (written commun., 1968). The collection contains, among other poorly preserved brachiopods, *Acrospirifer* sp., *Megakozlowskiella* sp., *Cyrtina* sp., *Coelospira* sp., and *Meristella* sp. The ostracodes present are *Bollia zygocornis* Swartz, *Ulrichia* sp., *Pyxiprimitia* sp., *Craterellina* sp. aff. *C. robusta* Ulrich and Bassler, and *Thlipsurella putea* Coryell and Cuskley. The presence of *Acrospirifer* suggests that this collection is post-New Scotland in age. Although *Thlipsurella putea* is a Haragan (correlative of the New Scotland) species, *Bollia zygocornis* is from the upper part of the Shriver Chert of Maryland and central Pennsylvania; the presence of the other ostracodes also agrees with this correlation.

## Oriskany Group

### *Shriver Chert*

Sandstone, chert, and siliceous and argillaceous limestone overlying the New Scotland Formation in the Lehigh Gap area and the Port Ewen Shale in the Delaware Water Gap area were included in the Meridian Series of Rogers (1858) and in the Oriskany Sandstone and Stormville Shale of White (1882). The name Oriskany was first proposed by Vanuxem (1839) for the sandstones at Oriskany Falls, New York.

Near Stroudsburg in easternmost Pennsylvania, the Oriskany Group is transitional into the underlying Port Ewen Shale through a sequence of interbedded sandstone, chert, argillaceous limestone, and calcareous shale. Sandstone is more abundant upwards and dominates the section at the top. Cleaves (1937) summarized the nomenclatural history of the Oriskany in Pennsylvania, recognized the twofold nature of the group, and divided it into the Ridgeley Formation above and the Shriver Formation below. The base was placed at the bottom of the lowest chert above the Port Ewen. Later, Cleaves (1939) was hesitant in assigning the lower Oriskany to the Shriver and placed these rocks in the lower part of the Ridgeley Formation, having explained (Cleaves, 1938, p. 1109) that ". . . the Shriver can not be established because of paleontological deficiencies. . . ." Swartz and Swartz (1941) used the names Oriskany Sandstone and Oriskany Shale for the corresponding units. Willard (1952) also maintained that the Shriver was absent in eastern Pennsylvania. According to Swartz and Swartz (1941), their Oriskany Shale is similar lithically and has the same stratigraphic position as the Shriver, but the fossils are sparse and do not aid in correlation. Accepting the thesis that age does not make a formation, Epstein and Epstein (1967, 1969) retained the name Shriver in eastern Pennsylvania in the way Cleaves first described it, because it is an easily recognizable sequence. The name Shriver *Chert* was retained following the original usage of Swartz (1913). It was named for exposures at Shriver Ridge, at Cumberland, Maryland.

In the Lehighton and Palmerton quadrangles, the upper 6 feet of the Shriver Chert is exposed along the Northeast Extension of the Pennsylvania Turnpike and the upper 3 feet in the Alliance Sand Company quarry immediately north of Palmerton. These rocks consist of white, irregularly bedded to nodular, fossiliferous (with spiriferid brachiopods) chert and very pale yellowish orange (10YR9/6) to grayish-orange (10YR7/4) medium- to very coarse grained conglomeratic sandstone. Beds are as much as 1 foot thick. Red and brown iron staining is common. Sand grains float in the chert and are replaced by the chert (Figure

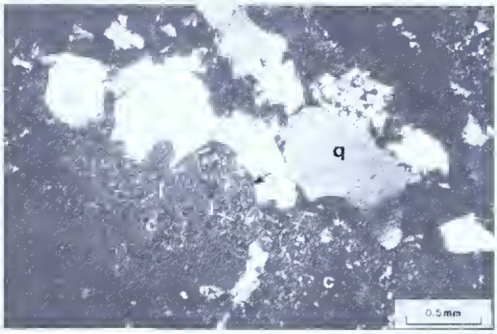


Figure 78. Photomicrograph (crossed polarizers) of cherty very coarse grained sandstone (probably an orthoquartzite) in uppermost 2 feet of Shriver Chert of the Oriskany Group, Alliance Company sand quarry, 2,000 feet northeast of the Hazard School in Palmerton. The quartz (q) grains have strongly undulose extinction. Chert (c) embays and replaces the quartz grains as well as silica overgrowths (arrow). The contact between the chert and quartz is marked by a thin limonitic "clay" rind, similar to a stylolite. Limonite specks (l) are scattered throughout the chert. Subhedral zircon is rare.

78). Quartz pebbles are as much as $3/8$ inch in diameter. These are generally well rounded; finer quartz grains are subangular to rounded.

As seen in thin section, the sandstones in the Shriver range from orthoquartzites to protoquartzites (Figure 78). The quartz grains are mostly single grains having strongly undulose extinction. Vermicular chlorite inclusions are common, as are silica overgrowths. The matrix, which is estimated to range from about 3 to 10 percent, consists of finer quartz grains and iron-stained mica. The chert replaces quartz grains and consists of a mosaic of irregular quartz crystals less than 0.002 mm long to more than 0.07 mm.

Because only the upper part of the Shriver Chert is exposed, the thickness is not directly obtainable. At the clay pits of the Universal Atlas Cement Company near Kunkletown, Pennsylvania, 4.7 miles east of the Palmerton quadrangle, the Shriver is 46 feet thick (Epstein and Epstein, 1969, Figure 53). It thins westward and is probably about 25 feet thick in the Lehighton and Palmerton quadrangles.

The contact between the Shriver Chert and overlying Ridgeley Sandstone is abrupt and is placed at the base of the predominantly sandstone interval of the Ridgeley.

## ENVIRONMENTS OF DEPOSITION AND PALEOGEOGRAPHY OF ORDOVICIAN THROUGH LOWER DEVONIAN ROCKS

An interpretation of the depositional environments and paleogeography of the rocks in the Lehighton and Palmerton quadrangles may be made by study of their sedimentary structures, regional stratigraphic relations, petrographic characteristics and faunal content, and by comparing these rocks with sediments that are being deposited today. The details on which these interpretations are based are given in the preceding section on bedrock stratigraphy. In general, the Middle Ordovician through Lower Devonian strata are a sedimentary cycle related to the waxing and waning of Taconic tectonism. The sequence begins with a graywacke-argillite suite (Martinsburg Formation) representing synorogenic basin deepening. This was followed by basin filling and progradation of a sandstone-shale clastic wedge (Shawangunk Formation and Bloomsburg Red Beds) derived from the erosion of the mountains that were uplifted during the Taconic orogeny. The sequence closed with deposition of many thinner units of carbonate, sandstone, shale, and chert on a shelf probably marginal to a land area of low relief. Another tectonic-sedimentary cycle, related to the Acadian orogeny, began with deposition of Middle Devonian rocks.

Rocks older than the Martinsburg Formation are exposed south of the Lehighton and Palmerton quadrangles. The rock record indicates that this area was a tidal flat and shallow shelf during the Cambrian and Early Ordovician (Hardyston Quartzite, Leithsville Formation, Allentown Dolomite, and Beekmantown Group: dolomite, limestone, orthoquartzite, and arkose). Just prior to deposition of the Martinsburg Formation, the onset of basin deepening is marked by calcilutite and calcarenite of the Jacksonburg Limestone. Flysch-type sedimentation and basin deepening culminated in Martinsburg time.

## Martinsburg Formation

The Martinsburg Formation is a thick monotonous flyschlike sequence of shale (metamorphosed to slate) and graywacke-sandstone and siltstone, probably 12,000 to 13,000 feet thick in the Lehigh Valley. McBride (1962) studied the Martinsburg of Pennsylvania and adjacent states and concluded that these rocks were deposited in deep water, partly by turbidity currents. Van Houten (1954) arrived at a similar conclusion in the Delaware River area of New Jersey.

The laminated and poorly fossiliferous shales (only graptolites have been found) were the "normal" slow rain of (hemi-) pelagic muds deposited in the quiet bathyal and perhaps abyssal waters below wave base, probably more than 1,000 feet deep. The graywackes are immature sediments that contain sedimentary features characteristic of turbidity currents, such as graded bedding (although grading may not be apparent in many units because of the fine-grained nature of the rock), parallel and cross lamination, sole marks, shale pebbles, sandstone dikes, and, negatively, absence of shallow-water fauna except allochthonous clasts of comminuted crinoids and brachiopods probably derived from the adjoining continental shelf, as well as absence of such shallow-water sedimentary features as winnowed sand and mud cracks. The graywacke turbidites were apparently dumped on top of the shales (sharp contacts between the graywackes and underlying shales are common) as a viscous fluid flow. They were derived from shallower depths, triggered into movement by earthquakes associated with Taconic tectonism, or perhaps by storms or undercutting of steep slopes, and aided in their movement by liquefaction under gravity. The graywackes are thus blanket deposits that were spread out over the deep sea floor and suddenly covered the underlying muds. The beds in the Martinsburg are fairly even and persist for distances greater than the length of individual outcrops, but because of poor exposure, lateral continuities are not known. Behre (1933) mapped beds for distances greater than several miles between the slate quarries that were active at the time. Paleocurrent data led McBride (1962) to the conclusion that the Martinsburg trough paralleled the present outcrop belt and that the sediments were derived from sourcelands to the southeast, although some of the material was transported parallel to the axial part of the trough.

The mineralogy of the Martinsburg graywackes, dominated by muscovite, chlorite, quartz, and calcite, with minor amounts of biotite, high sodic plagioclase, and a mature heavy-mineral suite (mostly rare zircon and tourmaline), along with chert and rock fragments of shale and possibly slate, indicate a source that included sedimentary and low-grade metamorphic rocks and possible contributions from volcanic rocks.

## Shawangunk Formation

In Late Ordovician time, the Taconic orogeny reached its peak, and the area was uplifted above sea level; the Martinsburg is succeeded by a molasse and carbonate-orthoquartzite sequence of Silurian (possibly latest Ordovician) to early Middle Devonian age. The inferred environments of deposition of these rocks in the area between the Delaware River and Lehighton quadrangle in eastern Pennsylvania is shown in Figure 79. Most of these interpretations are given by Epstein and others (1967) and Epstein and Epstein (1967, 1969, 1972).

The clastic sequence (molasse) in the Lehigh Gap area consists of three distinct units: a basal conglomerate and sandstone (Weiders and Minsi Members of the Shawangunk Formation); very fine to medium-grained sandstone, siltstone, and shale (Lizard Creek Member of the Shawangunk Formation); and an upper red-bed sequence of fine- to coarse-grained sandstone, siltstone, and silty shale (Bloomsburg Red

Beds). These form a wedge of terrigenous sediment derived from sourcelands to the southeast. This clastic wedge is considered to be predominantly fluvial in origin, but the Lizard Creek Member is a transitional marine-continental facies and parts of the Bloomsburg may have been deposited in a shallow-marine environment. The following discussion of the Shawangunk Formation is condensed from Epstein and Epstein (1972, p. 16-23).

Previous workers have considered the Shawangunk to be deltaic, fluvial, littoral, or tidal in origin. Regional stratigraphic relations, sedimentary structures, and petrographic characteristics discussed in the section on stratigraphy suggest that the Shawangunk Formation is a wedge of clastic material, shed during a period of intense alluviation from a linear highland source to the southeast that was uplifted during the Taconic orogeny, and was deposited by rapidly flowing streams (Weiders and Minsi Members) and also in a transitional marine-continental environment (Lizard Creek Member) (Figure 79).

Uplift in the source area initially was rapid, as indicated by the large pebbles in basal beds of the Weiders Member. Shallow-marine sediments that would have heralded the arrival of the first fluvial sediments presumably overlay the Martinsburg Formation at one time but were eroded by the streams that ultimately deposited the basal Shawangunk. Thus, there is a marked unconformity between the two formations. In general, the Shawangunk is finer grained higher in the section, representing a transgressive phase and suggesting that the uplifting orogenic forces had peaked and that the source area was progressively lowered concomitant with basin subsidence. A regressive phase, or progradation of fluvial sands over marginal marine sediments of the Lizard Creek Member, is indicated by the overlapping of coarse-grained rocks of a tongue of the Tammany Member (see Figure 7).

The Weiders Member of the Shawangunk Formation is characterized by sharp alternations of polymictic conglomerate with quartz pebbles as much as 6.5 inches long, medium- to very coarse grained submature to immature sandstone, and minor argillite. The bedforms, indicative of rapid flow and including a possible antidune (see Epstein and Epstein, 1969, Figure 50), sedimentary structures (planar bedding, indistinct bedding, crossbedding, scour-and-fill), and petrographic characteristics of the sandstones and conglomerates, as well as the nearly complete absence of fine siltstone and shale, indicate deposition by streams that had high competency, steep gradients, and erratic fluctuations in current flow and channel depth. These features are characteristic of braided streams with many anastomosing channels or anabranches surrounding alluvial islands or bars. Rapid runoff was undoubtedly aided by the lack of land vegetation during the Silurian. The few thin pelites present are mere relicts

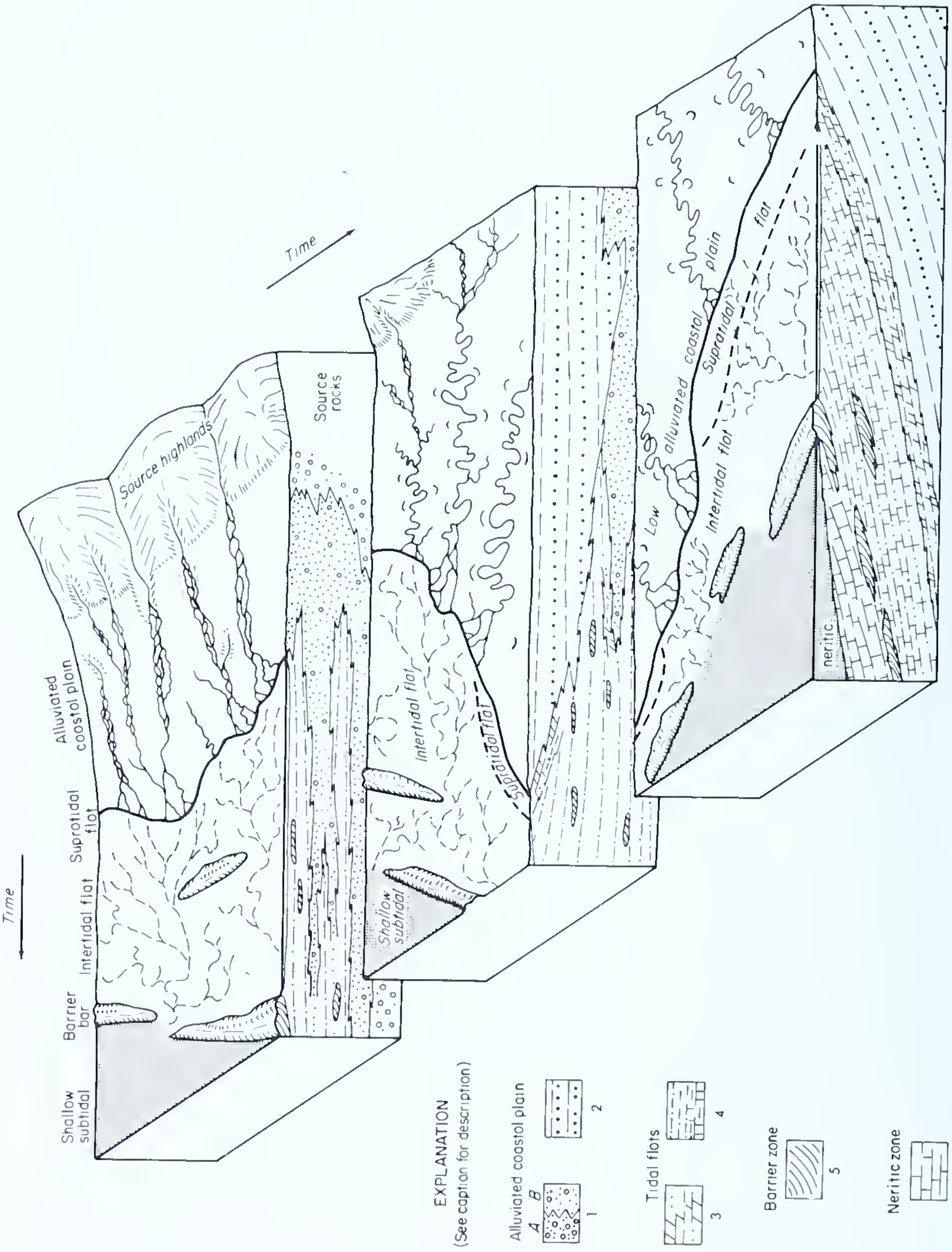

Time
Shallow subtidal
Barrier bar
Intertidal flat
Supratidal flat
Alluviated coastal plain
Source highlands
Source rocks
Time
Shallow subtidal
Intertidal flat
Supratidal flat
Low alluviated coastal plain
Supratidal flat
Intertidal flat
neritic
EXPLANATION
(See caption for description)
Alluviated coastal plain
A
B
1
2
Tidal flats
3
4
Barrier zone
5
Neritic zone
6

Figure 79. Generalized block diagram showing sedimentary environments and major lithofacies in northeasternmost Pennsylvania from Silurian through Early Devonian time. Sedimentary features of those deeply weathered and poorly exposed formations in the Lehighton and Palmerton quadrangles are inferred from exposures farther east. Modified from Epstein and Epstein (1969).

Alluviated coastal plain:

1. Streams of high gradient, coarse load, low sinuosity (braided).
   - A. Bedforms in upper flow regime (planar beds, possible antidunes) and upper lower flow regime (dunes). Chiefly conglomerate and sandstone. Weiders Member of the Shawangunk Formation.
   - B. Bedforms in lower upper flow regime (planar beds) and upper lower flow regime (dunes). Chiefly conglomeratic quartzite and quartzite. Minsi Member of the Shawangunk Formation, Lizard Creek Member of the Shawangunk Formation (part).
2. Streams of low gradient, medium load, and fine floodplain deposits, high sinuosity (meandering). Bedforms in lower flow regime (dunes and ripples). Sandstone, siltstone, and shale. Bloomsburg Red Beds and possibly Decker Formation (Andreas Red Beds of Swartz and Swartz, 1941).

Tidal flats

3. Supratidal flat, may include tidal creeks. Dolomite, limestone, shale, sandstone. Laminated (algal), massive, mud cracked, intraclasts, sparse fauna. Lizard Creek Member of the Shawangunk Formation, Poxono Island Formation.
4. Intertidal flat, may include tidal channel and gully, estuary, lagoon, beach. Shale, siltstone, sandstone, limestone in areas of low terrigenous influx, minor nodules and oolites of collophane, siderite, and chlorite. Irregularly bedded and laminated, graded, rippled, flaser-bedded, cut-and-fill, ball-and-pillow structure, burrowed, restricted fauna (abundant leperditiid ostracodes in carbonates; *Lingula* in noncarbonates; Dipleurozoa and eurypterids in noncarbonates at Delaware Water Gap to east). Lizard Creek Member of the Shawangunk Formation, Poxono Island Formation, Bossardville Limestone, Decker Formation.

Barrier zone

5. Offshore bar and beach. Sandstone, siltstone, conglomerate. Foreshore laminations, crossbedding, some burrowing, scouring, wave-tossed shell debris, some textural maturity. Lizard Creek Member of the Shawangunk Formation, Decker Formation, Stormville Member of the Coeymans Formation, Oriskany Group.

Neritic zone

6. Cherty calcareous shale and siltstone, laminated to unevenly bedded, partly burrowed, diverse fauna. Decker Formation, Stormville Member of the Coeymans Formation, New Scotland Formation, Oriskany Group. Deeply weathered and poorly exposed in Lehighton and Palmerton quadrangles so that many sedimentary features are obscure.

of any fine sediments that may have been deposited. Some of the mud was incorporated in the coarser sediment as flattened shale pebbles or mud balls (Figure 10).

Paleocurrent trends from crossbedding vectors in the Weiders, as well as in all units considered to be fluvial in the Shawangunk, are unidirectional to the northwest (Figure 80), as first recognized by Yeakel (1962) who supported a fluviatile environment for the Shawangunk. Pebbles in at least one bed of the Minsi Member are mainly oriented parallel to the current direction indicated by crossbedding, and a smaller mode is oriented at nearly right angles to that direction (Figure 81).

The Minsi Member is similar to the underlying Weiders except that the pebbles are smaller (less than 2 inches long), and argillites, representing overbank and backwater deposits, or mud deposited during waning flow in a channel, are more abundant. Mud cracks are present in the Minsi at Delaware Water Gap (Epstein and Epstein, 1969, Figure 8), showing that these deposits were subject to subaerial exposure. Numerous sedimentary units are superimposed, as in the Weiders Member, and here also represent deposition by braided streams. The finer grain size, however, suggests that the source highlands were lowered or eroded back at this time.

The coarse clastic rocks of the Minsi Member grade rapidly up into sandstone, siltstone, and shale of the Lizard Creek Member (Figure 25). This is interpreted to indicate that the Minsi alluviated coastal plain merged into braided flats in a complex transitional (continental-marine) environment (Figure 79). The following subenvironments were probably represented: tidal flat, barrier bar or beach, estuary, tidal channel and gully, lagoon, and shallow subtidal.

Both currents and waves formed the sedimentary structures on the tidal flats, producing irregularly bedded, laminated, and lenticular sandstone, siltstone, and shale. Flaser bedding (ripple lensing) (Figure 26), scour-and-fill structure, minute load casts, and crossbedding are common and are analogous to features in modern sediments reworked by tidal currents, especially in tidal channels. Laminated shales to fine sandstones, locally common in the Lizard Creek, were probably deposited from suspension under tranquil water conditions, such as found in lagoons. Some of the laminated red beds may have been deposited in high tidal flats and partly bound by algae. Similarly, red burrow-mottled siltstones may have formed as supratidal deposits in the oxidizing zone above mean-tide level; these would be landward equivalents of intertidal green beds.

Burrow mottling indicates that the tidal flats were reworked by organisms whose remains have not generally been preserved. The few fossils that have been found are consistent with the interpretation of a tidal-flat environment: linguloid brachiopods, *Arthrophycus,* eurypterids, and Dipleurozoa.

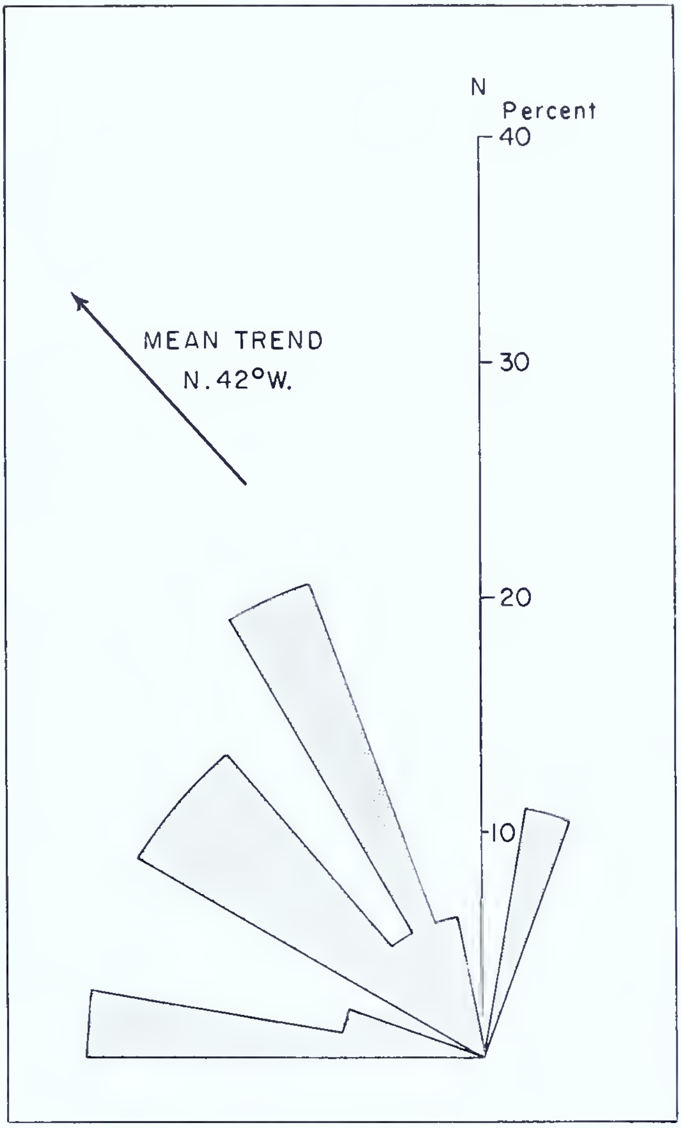


Figure 80. Histogram showing current trends from crossbedding in the Shawangunk Formation at Lehigh Gap (18 readings). Beds rotated to horizontal.

Some crossbedded sandstones with pronounced truncated bases and containing flattened mud clasts or mud galls (derived either from reworked curled mud cracks or from slumped mud banks undercut by tidal creeks) may be tidal-channel or tidal gully deposits. Many of the sandstones at Lehigh Gap grade up into flaser-bedded and laminated siltstone, fine sandstone, and shale, and are probably fining-upward deposits of meandering tidal creeks. These intervals are generally a few feet thick.

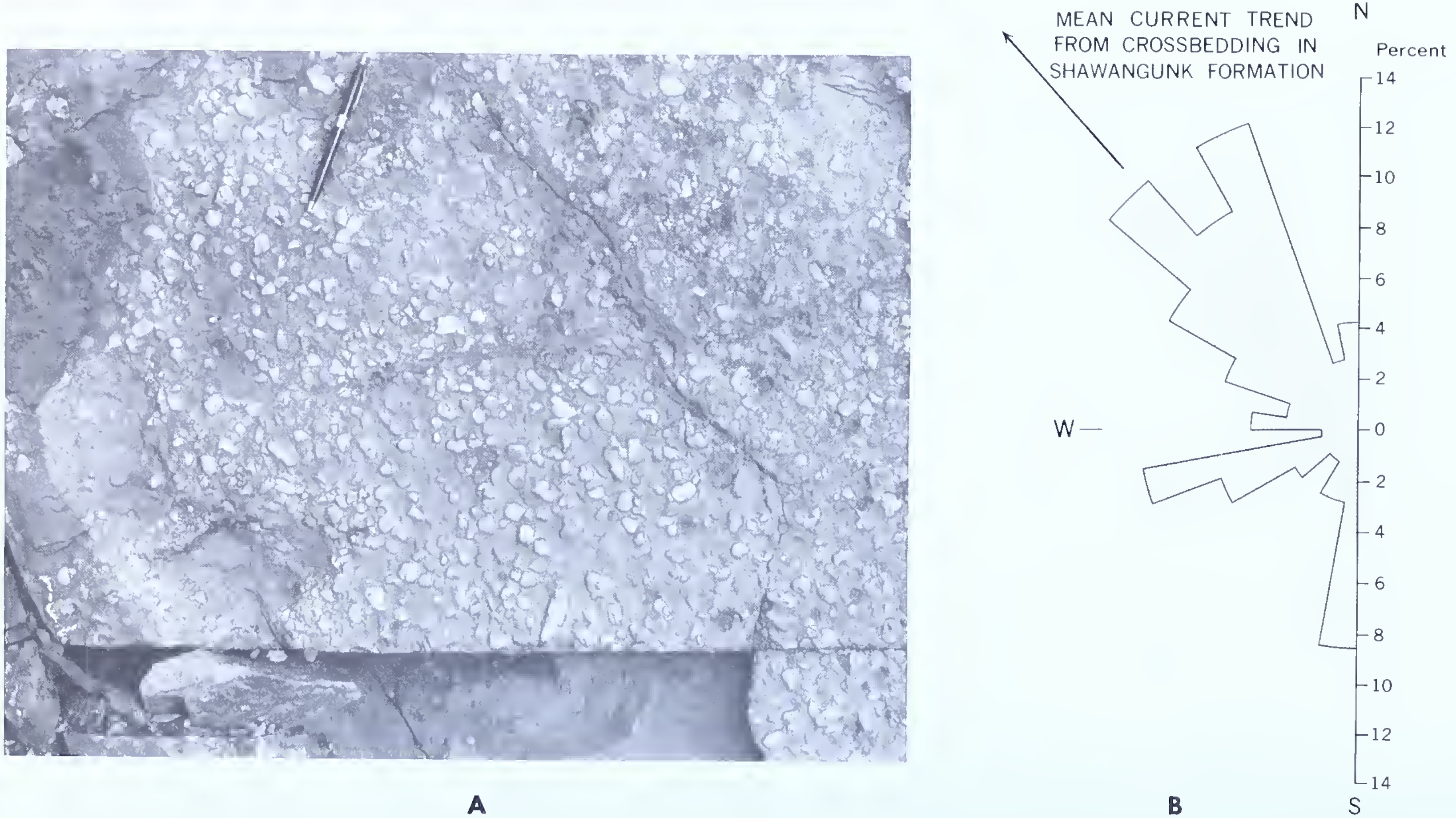


Figure 81. Pebble orientation in the Minsi Member of the Shawangunk Formation. A. Bedding surface of quartz-pebble conglomerate in the basal part of the Minsi Member. Pen points down to the northwest in the direction of current flow as determined by nearby crossbedding. Unit 15 of section 3, Epstein and Epstein, 1972, p. 31–41. B. Histogram showing orientation (in northwest and southwest quadrants) of long axes of 70 pebbles in bed shown in A. The mean current trend from crossbedding is from Figure 80.

Rock sequences at Lehigh Gap containing thick crossbedded sandstone (Figure 27) with mud clasts may have been fluviatile sediments that prograded onto the flats or may have been estuarine sediments that were carried into the transitional environments under the influence of currents generated by streams. These beds are tongues extending from the fluvial Tammany Member to the northeast (see Figure 7).

Many sandstones in the Lizard Creek that appear evenly textured and massive in outcrop are actually finely bedded to laminated. These are mature calcareous sandstones (generally orthoquartzites) containing heavy minerals concentrated in laminae, and some may have primary current lineation. They are interpreted as beach or bar deposits associated with the tidal flats.

Collophane (calcium fluorapatite), siderite, and chlorite nodules found at Lehigh Gap (Figures 38, 40) are unique to the Lizard Creek. Many soft-rock features shown in Figure 38 indicate that the nodules formed as early diagenetic replacements in an agitated environment and that transport of the nodules was slight. Shell fragments of linguloid brachiopods, probably *Lingula* (Figure 39), suggest that these nodules formed in shallow warm and possibly brackish waters, at depths probably less than 60 feet (Craig, 1952), or even in lagoons (Cocks, 1967). Of five Silurian benthonic marine communities recognized in Upper Llandovery (Lower Silurian) rocks in the British Isles, the *Lingula* community was regarded as "being the closest to shore, that is, adjacent to areas of nonmarine redbed deposition" (Ziegler and Boucot, 1970, p. 95). Thompson (1968) noted linguloid brachiopods in troughs or swales between sand bars in the lower intertidal zone of the Colorado River delta. Thus, finding *Lingula* reworked in beach sands (Figure 38A) is not unusual.

The collophane nodules appear to have formed as concretionary masses by precipitation of carbonate fluorapatite from sea water (Figure 38) and as replacements of siltstone and shale (Figures 38 and 40). The ultimate source of the phosphate was dissolved phosphorous either carried in by streams or brought into the shallow nearshore waters by downwelling currents from farther offshore (Gulbrandson, 1969). The phosphate was tied up in and concentrated in the hard parts of organisms such as *Lingula* and eurypterids, and was concentrated into nodules upon the death and decomposition of the animals. There can be little doubt that the phosphate nodules are of very shallow water origin (see Bushinski, 1964).

The long linear outcrop belt of the Weiders and Minsi Members suggests that these lower coarse clastic sediments of the Shawangunk Formation were deposited on a coastal plain of alluviation with a linear source to the southeast (Figure 79). The large pebbles in the Weiders (more than 6 inches long in places) suggest that the Fall Line may have been in the area of the Reading Prong not far to the southeast (see Yeakel, 1962). Abundant pelitic fragments in basal conglomerates argue against long-distance transport of these clasts. The maturity of the pebbles (quartz, chert, sandstone, and quartzite) and of the nonopaque heavy minerals (preponderance of zircon and tourmaline, many grains of which are rounded) suggests a sedimentary source. Biotite, fragments of metaquartzites, and rare grains of slate, as well as abundant sand-sized grains of detrital muscovite, indicate that the source rocks were partly made up of low-grade metamorphic rocks. The source area also had abundant quartz veins, because most of the pebbles are vein quartz with an irregular mosaic of interlocking quartz crystals; many pebbles contain inclusions of vermicular chlorite.

The Minsi Member at Lehigh Gap contains little or no feldspar, but some beds at Delaware Water Gap contain as much as 5 percent feldspar (Epstein, 1971), and northeastward in southeastern New York, orthoclase may form 24 percent of the rock (Muskatt, 1970) suggesting that the source was also partly composed of granitic or gneissic rocks. The mineralogical maturity of sandstones and conglomerates of the Shawangunk cannot be due to deep weathering of granitic or gneissic rocks in the source area because (1) well-rounded zircon, tourmaline, and pebbles of mature sandstone indicate multicycle transport; (2) feldspar in the Delaware Water Gap area shows that weathering was insufficient to remove it; (3) absence of kaolinite indicates that weathering was not intense enough to produce kaolinite from feldspar (however, any kaolinite that may have been present could have converted to muscovite by diagenesis or metamorphism following deep burial); (4) the large pebbles indicate short transport, bold valleys in the supposedly deeply weathered source area to supply the pebbles, and exposure of fresh bedrock in the valley walls; and (5) less stable minerals, such as feldspar, amphibole, and pyroxene, which would have been deposited with the quartz-bearing conglomerates and sandstone, should be abundant, but are not. The absence of limestone pebbles and the presence of chert supposedly derived from cherty limestones is difficult to explain. Possibly the chert was derived from bedded (radiolarian?) chert generally associated with marine pelites and graywackes, as suggested by the presence of minor siliceous slate fragments in the basal part of the Weiders Member at Lehigh Gap. The composition of Shawangunk conglomerates and sandstones thus does not seem to be compelling evidence for a deeply weathered source area.

Recognition of the precise source area for the Shawangunk is problematical and open to speculation. Feldspathic and quartzose metasedimentary rocks and smaller amounts of amphibolite, marble, and granitic rocks are now mainly exposed in the Reading Prong. Conceivably, equivalent rocks that may have been exposed during Silurian time could have been the source for some of the Shawangunk (see Berry and Boucot, 1970, Figures 7-11), and chert-bearing carbonates and quartzites of Cambrian and Ordovician age could have supplied other components. However, hornblende is extremely rare in the Shawangunk, and pyroxene and epidote, all common in Prong rocks, were not seen in any thin sections of Shawangunk rocks examined. Moreover, the Reading Prong characteristically lacks abundant quartz veins and is, therefore, not an enticing possibility as a source area for the Shawangunk. Could it be that rocks dissimilar to those now found to the southeast were the source for the Shawangunk, emplaced in their position in thrust sheets or nappes but long since eroded?

The scattered specks of graphite in the Lizard Creek Member are unique and indicate a metamorphic source, such as in the Piedmont of southeastern Pennsylvania, where Miller (1912) reported graphite in the Pickering Gneiss and Limestone ("Franklin Limestone") of Precambrian age. However, the Pickering is feldspar rich, and, as mentioned, the Shawaugunk contains rather small quantities of feldspar.

In summary, judging from the available data, it is concluded that during Shawangunk time the climate was warm and least semi-arid and that the source area had high relief. The mineralogy of the Shawangunk was controlled by the nature of the source rocks, which were composed predominantly of sedimentary and low-grade metamorphic rocks with abundant quartz veins and small local areas of feldspathic gneisses or granites. Erosion was intense, although enough broad interfluves may have been present so that a regolith developed that could supply iron to the depositional basin.

## Bloomsburg Red Beds

The tidal-flat and related deposits of the Lizard Creek Member grade up into red beds of the Bloomsburg Red Beds, representing a return to fluviatile conditions in eastern Pennsylvania. The Bloomsburg is finer grained than the alluvial rocks in the Minsi and Weiders Members of the Shawangunk Formation and consists of siltstone, sandstone, and shale in poorly to well-defined upward-fining cycles (Figure 48), suggesting that the southeastern source area was progressively lowered by erosion and that the braided stream deposits of the Shawangunk gave way to predominantly meandering stream deposits of the Bloomsburg (Epstein and Epstein, 1969; Epstein, 1971).

The cycles in the Bloomsburg are as much as 13 feet thick and consist of, from bottom to top:

(1) Very fine to coarse-grained, large-scale crossbedded to planar-bedded sandstone that locally contains red shale clasts as much as

3 inches long (Figure 45). The basal contact is a sharp erosion surface of very low relief that cuts into the underlying finer beds. The lower few inches of the sandstone are locally gray. The abruptness of the basal contact in places is accentuated by bedding slippage described in the section on structural geology.

(2) Finely interbedded and irregularly interlaminated siltstone and very fine grained sandstone containing small-scale ripples. Sandstone beds locally contain mud clasts.

(3) Shaly siltstone that is extensively burrowed (Figure 42), mud cracked in places (Figure 43), and contains scattered irregular dark-yellowish-orange concretions averaging about 1 inch in length (Figure 44). X-ray diffraction analysis and staining techniques show that the nodules are ferroan dolomite. The cycle described is somewhat idealized and does not represent all rocks in the Bloomsburg.

Cyclicity in the Bloomsburg is readily explained by vertical and lateral accretion from migrating streams concomitant with basin sinking. Each fining-upward cycle represents superposition of beds of successively lower flow regime.

These fining-upward cycles are generally considered to have been deposited by meandering streams (for example, Allen, 1965b). The coarser basal sands were deposited in stream channels and point bars through lateral accretion as the stream meandered. The mud clasts were derived from bank caving. Large-scale crossbedding and planar bedding are indicative of the upper lower and lower upper flow regimes, respectively. These basal beds grade up into laminated and intertonguing sandstone and siltstone containing small-scale crossbedding that indicates decreasing flow regime. Similar rocks have been interpreted to be levee and crevasse-splay deposits (Allen, 1965b). Next in succession are the fine overbank or floodplain deposits that accumulated by vertical accretion. Burrowing animals obliterated stratification in many of these beds in this low-energy, tranquil environment. Mud cracks show that subaerial exposure was common. Evaporation at the surface may have caused the precipitation of calcareous concretions similar to the formation of caliche in soils (see Bernard and Major, 1963; Allen, 1965b; Moody-Stuart, 1966), but, as mentioned previously, the concretions in the Bloomsburg are ferroan dolomite. It is possible that the Bloomsburg rivers were not far above the strandline and that the dolomite concretions may have formed in a high tidal-flat environment by upward-rising brines enriched in magnesium by a mechanism similar to that described for the penecontemporaneous dolomitization of limestone on supratidal flats (for example, see Shinn and others, 1965). Cyclicity in the Bloomsburg is readily explained by vertical and lateral accretion from migrating streams concomitant with basin sinking. Each fining-upward cycle represents superposition of beds of successively lower flow regime.

Fossils are very rare in the Bloomsburg. Fish scales were found at the Delaware Water Gap (Epstein, 1971), and Beerbower and Hait (1959) believed that the fish lived in a fluvial or lagoonal environment. Similar fish scales were not seen in the Bloomsburg at Lehigh Gap but could have been overlooked. Thus, some of the red beds in the Bloomsburg could have been deposited in shallow marine waters.

The lower boundary of the Bloomsburg with the Lizard Creek Member of the Shawangunk Formation at Lehigh Gap is transitional through 162 feet of red and green rocks and marks the change from a marginal marine environment to a low alluviated coastal plain. The greenish rocks are laminated, and flaser bedding and slump structures are due to movement of saturated sediments on the flats (Figure 47). The red color is believed to have been derived at the site of deposition as the result of oxidation of iron-rich minerals or conversion of hematite from goethite or "limonite" (Berner, 1969), rather than having been derived from red upland soils (Van Houten, 1964; Walker, 1967a, b). The red-green transition zone marks the oxidation-reduction boundary at or near mean-tide level (McKee, 1957; Nichols, 1962). Clearly, the land surface in Bloomsburg time was at low altitudes and near sea level.

As pointed out by Miller and Folk (1955) and others, the formation of red beds requires the presence of iron-rich minerals, hence an igneous or metamorphic source. The petrographic characteristics of the Bloomsburg are markedly different from those in the underlying Shawangunk, suggesting that the source area was eroded to lower levels and deeper igneous and/or metamorphic rocks were reached through a sedimentary cover. The sandstones in the Bloomsburg are mostly immature graywacke with appreciable potash and plagioclase feldspar and abundant rock fragments (Figure 50). The fragments include sedimentary shale, siltstone, and quartzite, volcanic felsite, and granitic or gneissic derivatives. Vein quartz is abundant. Nonopaque heavy minerals are muscovite, biotite, chlorite, zircon, and tourmaline.

The sediments deposited after the end of molasse sedimentation in Bloomsburg time, up to and including those of the Oriskany Group, are a shallow-marine shelf facies. During this time, the rates of sedimentation and basin sinking were about equal, so that the area was maintained near sea level, and an alternating complex of tidal flats (supratidal and intertidal), barrier bars, and subtidal zones was maintained (Figure 79). These were marginal to a low-lying stable land surface that supplied terrigenous material to the basin of deposition from time to time. These rocks are generally poorly exposed in the Lehighton and Palmerton quadrangles, but on the basis of the few outcrops and sedimentologic details to the east (Epstein and others, 1967; Epstein and Epstein, 1969), a general environmental interpretation can be made.

## Poxono Island Formation

Encroachment of the sea over broad tidal flats during Poxono Island time initiated the general Late Silurian and Early Devonian transgression. Red beds in the lower part of the formation suggest deposition in the oxidized zone above high tide, probably by streams. The laminated and finely bedded, partly mud cracked dolomite, limestone, and calcareous shale (Figures 52, 53, 57) that are predominant in the formation are interpreted to have formed on intertidal and supratidal flats. The laminae probably formed by trapping of muds by algae on the flats after transportation of the muds from the intertidal and subtidal zones during storms and spring tides. This process has been described in modern flats by Black (1933), Logan (1961), and Kendall and Skipwith (1969). Some or most of the mud may have been directly precipitated by biochemical processes within the algal mats, as described by Monty (1967) in the supratidal zone of Andros Island, Bahamas.

Between floodings, exposure and desiccation of the mats and bound sediment produced mud cracks (Figure 53) which are also well documented on many recent flats. The Poxono Island mud cracks are deep (generally more than 3 feet) and may have been protected and perpetrated by algae, probably in the same manner described by Black (1933) and Kendall and Skipwith (1969) in modern sediments. Successive algal mats mimicked the underlying mud-crack form, and subsequent mud cracking followed pre-existing shrinkage lines. This mechanism, as well as possible accentuation due to cleavage development parallel to mud-crack columns, could also explain the long columns in the overlying Bossardville Limestone.

The dolomites in the Poxono Island are believed to have formed by penecontemporaneous replacement on the supratidal flats, as described by Illing and others (1965), Kendall and Skipwith (1969), and Kinsman (1969) in the Persian Gulf; Deffeyes and others (1965) in Bonaire, Netherlands Antilles; and Shinn and others (1965) in the Bahamas. During drying, brines in the sediment pores migrated upward by capillary action, resulting in the growth of calcium-rich minerals (anhydrite or gypsum). Most of the minerals were dissolved and flushed from the sediment by freshwater surface runoff, although some have been found in the subsurface (measured section 24). Precipitation of these minerals enriched the brines in magnesium at the surface, and when the Mg/Ca ratio reached a value of about 11, dolomitization of the calcium carbonate mud could take place (Kinsman, 1966).

The graded limestones with micro scour-and-fill, intraclasts, and burrow mottling are intertidal deposits similar to those described in the overlying Bossardville Limestone.

## Bossardville Limestone

The Bossardville is a very thin bedded to laminated argillaceous limestone and lesser calcareous shale (Figures 57 and 58). These rocks, and similar ones in the underlying Poxono Island, are generally graded. The base of a graded unit is sharp (Figure 59). Micro cross laminations and scour-and-fill are common, indicating alternating currents typical of tidal flats. Basal rocks of graded units are calcisiltites (Figures 62 and 63) and quartzose skeletal calcarenites (Figures 54, 59, 64 and 65) in which intraclasts, ripped up from the substrate, are common. These grade up into biomicrudites, biomicrites, and biopelmicrites (Figure 66) and then up into micrite (Figures 55 and 62) or calcareous shale (Figure 59).

Bioclastic debris is abundant in most basal beds, and is less abundant in overlying finer rocks. Most is apparently reworked and moved about the flats by tides or storms. The most abundant fossils are leperditiid ostracodes (Figures 54, 63, 64 and 65); few "normal" neritic marine fossils are present. The leperditiids were well adapted for survival in shallow areas that underwent repeated exposure. They had very thick overlapping valves and well-developed muscles for keeping the valves tightly shut—all features for protection against desiccation. Berdan (1968) has also suggested that the large smooth shells and subsidiary muscle scars "indicating strong appendages capable of digging" were possible adaptations for burrowing on tidal flats. Burrow mottling is present in some of the limestones in the Poxono Island and Bossardville.

Some intraclasts in the Bossardville are encrusted with bryozoans or possibly algae (oncolites), suggesting reworking of the sediment in very shallow water, possibly in subtidal tidal channels, or in subtidal areas marginal to the intertidal flats (see Laporte, 1967, Figure 29, for a schematic cross section of the shallow subtidal, intertidal, and supratidal environments).

## Decker Formation

The basal 5 feet of the Decker Formation at measured section 4 contains a few graded beds similar to those in the Bossardville (Figure 68), probably intertidal deposits, interbedded with very fossiliferous limestone (Figure 69) and oosparites (Figure 70). The fossils include brachiopods, bryozoans, and rare conodonts, and indicate shallow subtidal deposits. Perhaps these fossils were heaped onto the tidal flats during storms, but the presence of stromatoporoids suggests deposition in very shallow subtidal waters, either in tidal channels or directly seaward of the intertidal flats (Laporte, 1967). The limestones are more winnowed upwards in these basal beds (biomicrudites giving way to grain-supported and well-sorted oosparites with abundant intraclasts higher up), suggesting a shallow subtidal high-energy environment. These beds also contain more and coarser silt and sand than the underlying Bossardville, showing an increase of terrigenous influx foreshadowing deposition of the overlying siltstones and sandstones. The siltstones and sandstones are burrowed, have many small-scale cut-and-fill structures, and contain a variety of fossils, including corals, crinoids, ostracodes, and brachiopods. These are considered to be shallow shelf silts and sands that accumulated offshore of the Bossardville mudflats. (Correlative rocks of the Bossardville Limestone, therefore, probably existed southeast of the present Decker outcrop belt, but have been removed by erosion.) These may be pro-bar sediments (lower and middle shoreface) of an offshore bar (see Davies and others, 1971, Figure 3). The overlying upper shoreface and possibly beach deposits are not exposed but may be present under cover. The sands in the Decker are coarser grained and more conglomeratic higher in the section. This coarsening upwards is typical of bars. The Decker is extensively burrowed 13 feet above its base (Figure 72) and partly burrowed 25 feet above the base (Figure 73). A strikingly similar sequence of rocks is illustrated by Davies and others (1971, Figures 7 and 8) and is shown to be back-bar deposits (lagoonal) and washover sands derived from the adjacent barrier during storms. The abundance of marine fossils in these rocks of the Decker, however, suggests that they are shallow shelf sands and silts flanking the beach in a seaward direction. It would be helpful to have adequate exposures to see the lateral sedimentologic variations of these rocks. To the east in Pennsylvania, the Decker consists of crossbedded, planar-bedded, and flaser-bedded sandstone with lenses of fossil hash and quartz-pebble conglomerate. It has been interpreted to be mostly a barrier bar (Epstein and others, 1967; Epstein and Epstein, 1969).

The Andreas Red Beds, included in the top of the Decker, may be a fluvial deposit that extended out over the beach and shallow marine sediments of the lower Decker. Exposures are poor, however, so this interpretation (as well as the age of the Andreas) is insecure.

## Stormville Member of the Coeymans Formation

Most sedimentary features are obliterated by leaching in this poorly exposed unit, but to the east, similar sandstones and finer clastic materials have been interpreted to be a barrier-bar deposit (see Epstein and others, 1967; Epstein and Epstein, 1969). Possibly some of it was deposited in a shallow neritic environment.

## New Scotland Formation

The New Scotland Formation is not exposed in the area, but on the basis of exposures to the east (Epstein and others, 1967), the calcisiltites of this formation represent a deeper neritic phase below wave base following Stormville deposition as the rate of basin submergence exceeded the rate of sediment supply.

## Oriskany Group

The Ridgeley Sandstone of the Oriskany Group has been shown to be a bar or beach deposit in easternmost Pennsylvania (Epstein and Epstein, 1969). The irregularly bedded to nodular fossiliferous chert and conglomeratic sandstone of the Shriver Chert, intervening between the Ridgeley beach deposit and deeper water deposits of the New Scotland, is believed to be the transitional shallow subtidal pro-bar apron. The presence of abundant thick-shelled brachiopods (*Spirifer arenosus*) favors this view that these rocks were deposited in a wave-tossed agitated nearstrandline environment.

## Summary

The sedimentary environments of Middle Ordovician through Lower Devonian rocks were controlled by Taconic orogenic evolution, beginning with the formation of a deep synorogenic flysch basin, uplift of source highlands to the southeast, gradual erosion of those highlands and decrease of the northwest paleoslope, and a general shallow marine transgression of a shallow epeiric sea. The general progression of environments following uplift was first fluvial deposition, interrupted and followed by transitional marine deposition (mainly on tidal flats and barrier bars or beaches), then deposition in a "normal" marine environment below tidal influence, and finally a tendency toward shoaling late in the period. Figure 82 summarizes the environmental record for this period of time in the Lehighton and Palmerton quadrangles.

The Upper Silurian and Lower Devonian outcrop belt in eastern Pennsylvania crosses several depositional zones, as indicated above. The shorelines trended more to the east than the outcrop belt in the Lehighton and Palmerton quadrangles (Figure 83). The axis of the depositional basin during this time remained fairly constant and extended northeastward across central Pennsylvania. A low-lying positive area appears to have controlled sedimentation during latest Silurian and Early Devonian time in the Lehighton and Palmerton quadrangles. Stratigraphic anom-

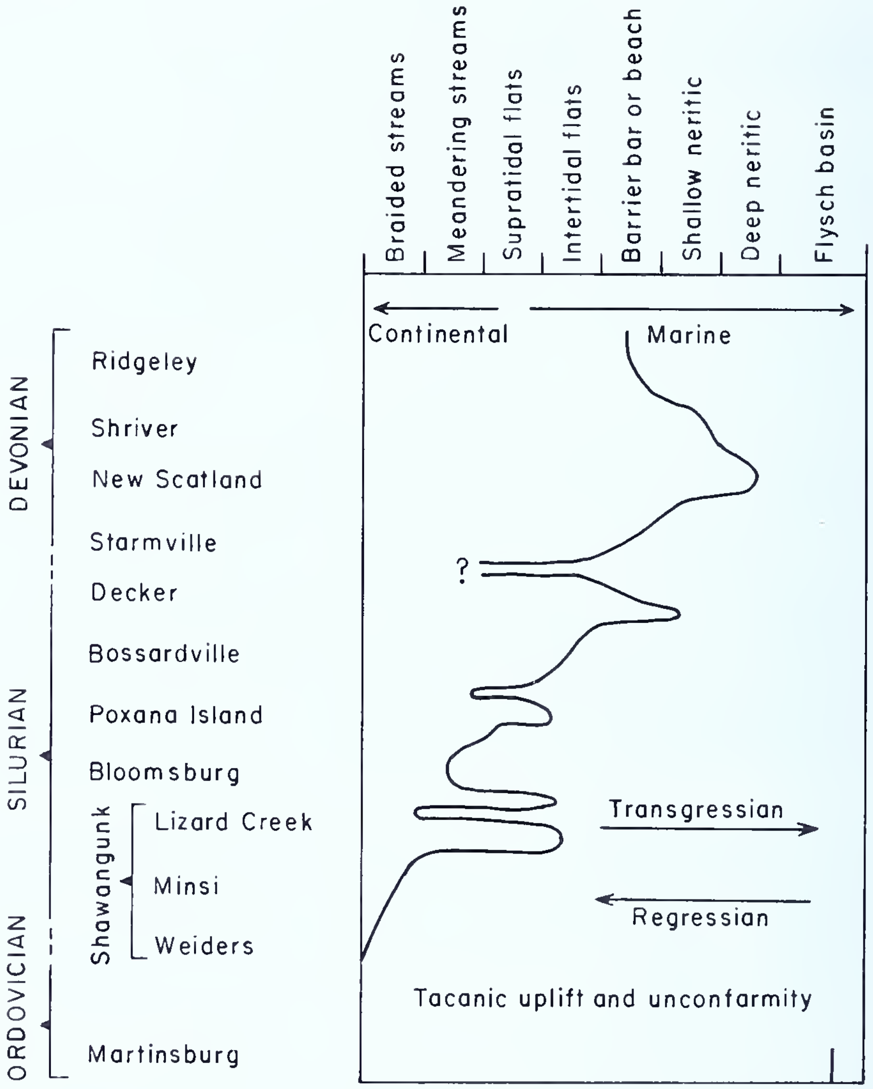


Figure 82. Environmental changes from Middle Ordovician to Early Devonian time in the Lehighton and Palmerton quadrangles.

alies in the vicinity of this positive area were recognized by the First and Second Pennsylvania Geological Surveys, and the area was termed the "Harrisburg axis" by Ulrich (1911) and Willard (1941) and named the "Auburn Promontory" by Swartz (1939). The Auburn Promontory was figured in isopach maps by Wood and others (1969). The axis of the Auburn Promontory lay about 35 miles southwest of the Lehighton quadrangle (Figure 83). Much of the terrigenous material in the post-Bloomsburg rocks in the Lehighton and Palmerton quadrangles may have been derived from this positive area, as well as from the low-lying landmass immediately to the southeast. Swartz (1939) and Willard (1941) recognized that many stratigraphic units thinned and became more clastic to

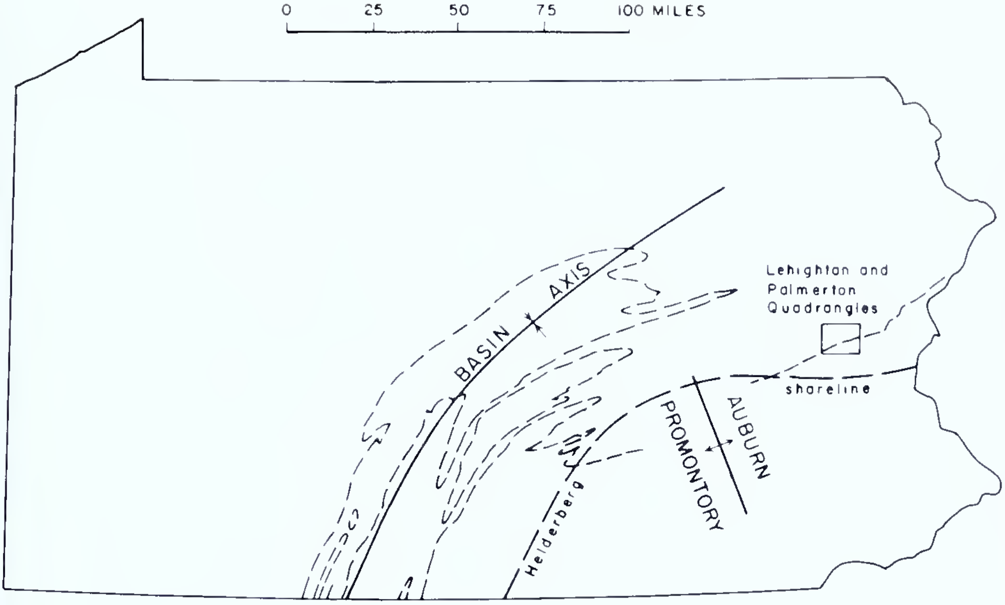


Figure 83. Map (nonpalinspastic) of Pennsylvania showing outcrop belt of uppermost Silurian and Lower Devonian rocks (short dashed line), the approximate position of the axis of the depositional basin during deposition of these rocks, the position of the Auburn Promontory (the exact location of the axis is speculative), the inferred position of the shoreline during a part of Coeymans time (long dashed line), and location of the Lehighton and Palmerton quadrangles. Compiled from Swartz (1939), Jones and Cate (1957), Gray and others (1960), and Rickard (1969).

the southwest in approaching the promontory, and many of them disappeared by unconformity on the axis. Thus, many of the Upper Silurian and Lower Devonian units in the Palmerton and Lehighton quadrangles are thinner than they are to the northeast in the Delaware Water Gap area (see Epstein and Epstein, 1969, especially Figure 6), and many diastems or small unconformities are probably present in the section in the area of this report (see stratigraphic discussion of the New Scotland Formation).

## LOWER AND MIDDLE DEVONIAN

### Ridgeley Formation

The Ridgeley Formation is made up of white, bimodal, quartz sandstones and fine-grained pebble conglomerates which are characterized by brachiopod valve molds. The unit is seldom exposed in the area except for several outcrops, one of which is described in measured section 5. The unit generally occurs at the base of the steep southern slope of Stony

Ridge (also called Stone Ridge and Chestnut Ridge) and is covered with colluvium. The Ridgeley caps Stony Ridge only in the rare instances when it is better indurated than the Palmerton Formation which normally caps the ridge. Elsewhere in the mapped area the Ridgeley occurs in the subsurface and is known only from the Phillips Petroleum Company exploration well No. 1 Graver Estate (measured section 24). The stratigraphic nomenclature of the unit is reviewed in Plate 3.

The texture of the Ridgeley is variable both areally and within outcrops. The boundaries between sandstones and conglomerates are generally gradational; the gradation often occurs within 1 or 2 inches. Areal variation in the proportion of sandstone and conglomerate within the Ridgeley is indicated by the following data from measured sections: Stony Mountain School, 100 percent conglomerate; Lizard Creek Junction, 47 percent conglomerate and 53 percent sandstone; West Bowmans (measured section 5), 32 percent conglomerate and 68 percent sandstone; and Little Gap, 4 percent conglomerate and 96 percent sandstone.

A pronounced grain-size bimodality occurs in most of the Ridgeley sandstones. The grain sizes vary from fine (0.125 mm) to very coarse grained (2.00 mm) with a tendency for a greater concentration of material in the coarser sizes. Beds which are not bimodal are usually fine grained and appear to be well sorted. The individual grains are subangular to subrounded quartz. Some or all of the grain angularity may be due to secondary silicification. Rounded quartz granules or pebbles occur rarely in the sandstone beds.

The conglomerates consist of varying percentages (25 to 75) of rounded or subrounded quartz grains ranging in size from granules (2-4 mm) to medium-grained (8-16 mm) pebbles within a matrix of fine- (0.125 mm), medium- or coarse-grained (1.0 mm) quartz sand. Pebbles as large as 1½ inches in diameter are rare. The granules and pebbles are sometimes evenly distributed throughout the rock (floating in the sand matrix) and sometimes concentrated in bands.

Planes of parting are rare within the Ridgeley, with the result that the whole formation is basically massive. Some beds attain a thickness of 5½ feet, but generally the thickness of a bed of one lithology varies between 5 inches and 2 feet.

Molds of single valves of brachiopods varying from ½ to 1½ inches in length are one of the most characteristic features of the Ridgeley. These molds appear as shaped voids within the rock and occur: (1) scattered throughout a bed, in which case they are generally unoriented; and (2) aligned along a bedding plane, in which case they are oriented convexly upward. The molds generally occur in the conglomerates, but are completely enclosed by the matrix sand rather than pebbles. Willard and others (1939, p. 109-116) discuss the fauna of this unit.

The Ridgeley contains varying amounts of silica cement and ranges from friable to quartzitic in induration. Most of the rock presently exposed in the mapped area has been sufficiently weathered that it has a moderate porosity, and pebbles protrude on weathered faces. Rocks of the Ridgeley Formation disintegrate with moderate rapidity and do not form abundant float material, although small (less than 6 inches long) boulders commonly are present and are usually easily identified because of the brachiopod valve molds and the protruding pebbles.

Fresh rock of the Ridgeley is generally white to very light gray. The gray color becomes darker when weathered, and reddish and yellowish iron discoloration is present in some places.

The basal contact of the Ridgeley Formation with the underlying New Scotland Chert is exposed only along the Northeast Extension of the Pennsylvania Turnpike near Lizard Creek Junction where it consists of several sharply defined interbeds of chert and sandstone. The interfaces between the chert beds and the sandstone beds are sharp, but some coarse- to very coarse grained quartz grains are scattered through the chert beds and some chert-like cement occurs in the sandstone. The bond between the two contrasting lithologies is very strong; there is no tendency for parting along planes between lithologies. The base of the Ridgeley Formation is placed at the first sandstone bed. The upper contact is sharp and is an abrupt change from conglomerate to clay or siltstone of the overlying Schoharie-Esopus Formation.

The Ridgeley Formation thins to the southwest across the mapped area, and Sevon (1968a) suggests that the unit does not persist southwest of Andreas (about 5 miles southwest of Germans). Within the mapped area the Ridgeley is more than 50 feet thick at Little Gap, 21 feet thick at Lizard Creek Junction, and 8 feet thick near Stony Mountain School.

### *Microscopic Characteristics*

Thirteen thin sections of indurated Ridgeley rock from 3 localities were examined and 4 of the thin sections were analyzed by point count. A typical Ridgeley rock has 90 percent detrital grains and 10 percent matrix. The matrix is primarily secondary silica either in the form of quartz overgrowths or interstitial silica masses. Minor amounts of hematite and sericite also occur in the matrix. The detrital fraction contains 98 percent or more quartz, of which about 63 percent is composite metamorphic quartz (Folk, 1959) and 32 percent is strongly undulose common quartz. Fine-grained rock fragments and slightly undulose common quartz make up the remainder of the detrital fraction. Most of the pebbles are composite metamorphic quartz whereas almost all of the sand grains (0.062-2.00 mm) are common quartz. Some of the sand grains have minute vacuole strings and a number of grains have a "wormy" internal structure. The small wormlike holes are filled with a bluish mineral which is probably chlorite.

The pebbles are rounded to well rounded and the sand grains are angular to well rounded. The shape of many of the sand grains has been modified by secondary silica and the original shape is sometimes completely obliterated. The conglomerates generally have poor to moderate packing; many interstices have been filled with secondary silica. The sandstones have quartzitic textures with complete interlocking of adjacent grains and obliteration of original grain shape. Small amounts of iron occur as cement surrounding most grains in some Ridgeley rocks.

### *Sedimentology*

The mineralogical maturity, good sorting, and original roundness of grains of the Ridgeley indicate considerable reworking of the sediment prior to final deposition. The brachiopod fauna indicates origin in a marine environment, and the occurrence of single valves in stable-position orientation suggests moderate to high energy conditions. The stratigraphically adjacent units also suggest a marine environment for the sandstone. Aligned brachiopod valves generally define planar or low-angle bedding, although this bedding alignment is sometimes obscure. These characteristics indicate that the Ridgeley was deposited in a foreshore environment as suggested by Epstein and Epstein (1967) and Seilacher (1968).

## Schoharie-Esopus Formation

The Schoharie-Esopus Formation consists of a series of well-bedded, very fine to coarse-grained, gray to olive-gray, hard siltstones. The formation thins southwest from more than 76 feet at Little Gap to 43 feet at West Bowmans (measured section 5) to 12 feet at Stony Mountain School, and maintains a bipartite character throughout. The lower part is characterized by coarse-grained nonfossiliferous siltstones which contain abundant structures resembling overturned crossbeds, and the upper part is characterized by fossiliferous siltstones which are finer grained and lighter in color, and lack overturned crossbed structures. The two parts are usually separated by a thin red hematite-rich siltstone bed.

The stratigraphic nomenclature of this unit is reviewed in Plate 3. The Schoharie-Esopus Formation can be traced laterally from the mapped area into the differentiable Schoharie (above) and Esopus (below) Formations in the Stroudsburg area. In the mapped area formations are too thin to be mapped as separate units, although the upper and lower parts appear correlative to the Schoharie and Esopus Formations, respectively.

The Schoharie-Esopus crops out occasionally on Stony Ridge at places where the crest rock changes from Palmerton Formation to Ridgeley Formation, infrequently along the south side of Stony Ridge where the Palmerton Formation forms a prominent crest, in quarries at Germans, Palmerton, and Aquashicola, and in roadcuts such as on the Northeast Extension of the Pennsylvania Turnpike at West Bowmans (best complete exposure) and at Little Gap.

The base of the Schoharie-Esopus is marked by an abrupt change from sandstone of the underlying Ridgeley Formation to white clay or shale of the Schoharie-Esopus. This contact is best exposed on the Turnpike (measured section 5, units 10-11), although less deeply weathered shale crops out occasionally along the base of Stony Ridge. This clay results from extreme weathering of massive medium-gray (N5) to meduim-light-gray (N6) silty shales. The clay is stained various hues of red and yellow by iron and contains some coarse-grained quartz grains. A semi-quantitative X-ray diffraction analysis (by Pennsylvania Geological Survey) of this clay (sample from measured section 5, unit 10) gave the following results: mica (muscovite), 91 percent; kaolinite, 4 percent; quartz, 5 percent. Clay exposed in another Turnpike roadcut near Lizard Creek Junction contains hard, dark-gray (N3) claystone nodules up to 2 inches in diameter and 4 inches long.

Above the weathered basal part of the unit, the lower part of the Schoharie-Esopus is characteristically hard, well-bedded, medium-gray (N5) to dark-gray (N3) to olive-gray (5Y4/1 or 5Y3/1), medium- to coarse-grained siltstone (Figure 84). The beds have sharp bedding-plane partings and are generally 1 to 4 inches thick. Most of the beds contain abundant animal burrow mottling and a structure resembling overturned crossbedding. This structure is prominent because of alternation of light- and dark-gray colors. The dark color results from a small amount of organic material concentrated on top of cross laminations. Superposed sets of cross laminations often show completely opposite directions of dip, and the bases of many cross laminations show that erosional scour of the underlying bed occurred before formation of the overlying structure. The thickness of individual beds with cross-lamination structures is generally less than ½ inch. These thin beds show no parting tendency.

Animal burrows sometimes disrupt the cross-lamination structures, but fossils are rare in this part of the formation.

At Little Gap, this interval is pale red (5R6/2) to grayish-red purple (5RP5/2) and quartzitic in texture. The cross-lamination structures are evident in the lowermost part and in well-weathered float material, but are obscured in fresher rock by the quartzitic texture. The beds in this section are also more massive than in other sections; some beds are as thick as 2½ feet.

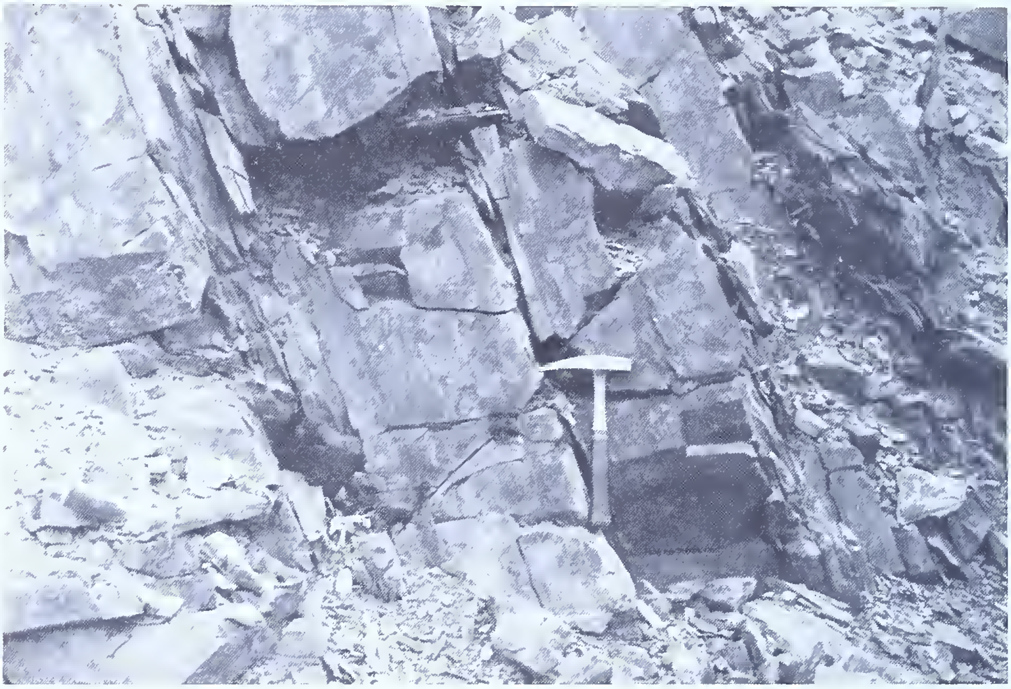


Figure 84. Outcrop of well-bedded Schoharie-Esopus siltstone along east side of Northeast Extension of the Pennsylvania Turnpike at West Bowmans.

In the eastern part of the mapped area (Little Gap), the lower part of the formation forms 65 percent of the whole; at the Turnpike, 62 percent; and southwest of Germans, 52 percent.

Except at the Little Gap section, the lower and upper parts of the Schoharie-Esopus Formation are separated by a 9- or 10-inch-thick grayish-red (5R4/2) hematite-rich siltstone bed.

The upper part of the formation is generally abundantly fossiliferous, well-bedded, fine- to medium-grained siltstone which lacks the cross-lamination structures typical of the lower part. The color of this part ranges from light gray (N7) to medium-dark gray (N4) to light-olive gray (5Y6/2). The lighter gray colors are most common and probably represent weathered colors for the most part. Most of the upper part of the formation at Little Gap has a color between grayish orange (10YR7/4) and grayish-orange pink (5YR7/2).

Animal burrow mottling is present in some of the lower beds of the upper part of the formation, but most beds lack internal structure. Fossils are almost exclusively brachiopod valves aligned along well-defined planes, but in some beds the valves are randomly scattered with no apparent orientation.

This formation becomes increasingly quartzitic towards the upper contact and often resembles chert in appearance. The more chertlike beds usually weather almost white in color.

The uppermost part of the Schoharie-Esopus Formation includes several siltstone and sandstone interbeds which are discussed more fully in the following section (Palmerton Formation). The upper contact of the formation is placed at the base of the first sandstone interbed.

The well-bedded Schoharie-Esopus is broken by innumerable joints. The rock itself is generally very hard and resists rapid disintegration into component grains, but the bedding and jointing allow easy disruption of the unit by physical weathering. Float materials developed from this unit usually are small (2 to 6 inches long) angular plates of light-gray siltstone, sometimes having ribbed surfaces (differentially weathered, overturned cross-lamination topsets) and sometimes having holes developed by weathering of brachiopod valves. The distinctive nature of the Schoharie-Esopus float material and its proximity to the underlying Ridgeley and the overlying Palmerton sandstones allow this unit to be mapped with some ease.

### *Microscopic Characteristics*

Thirty-eight thin sections of Schoharie-Esopus from 4 localities were examined. Nineteen thin sections were from the upper part of the formation, 16 from the lower part and 3 from the hematite-rich central part. The Schoharie-Esopus is a suite of rocks comprising detrital and matrix fractions that have little compositional variation. The main variation is the proportion of detritus to matrix.

The detrital fraction is made up of dominantly strained, angular quartz grains ranging in size from fine-grained silt (0.008 mm) to fine-grained sand (0.125 mm). The margins of most grains have solution-etching irregularity and margins of some grains are occasionally interpenetrated. Rare grains of plagioclase occurred in 2 thin sections. Epidote, garnet, and tourmaline were the only heavy minerals identified. Some slides contained no heavy mineral grains and in no slide was the quantity of detrital heavy minerals more than a fraction of a percent. Small irregularly shaped particles of hematite occur scattered throughout all of the slides, although the quantity and size of the particles varies from slide to slide. The amount of detritus is variable and estimates of percentages are summarized as follows: upper part, 51 percent (range, 1-95 percent); hematite-rich zone, 22 percent (range, 5-50 percent); and lower part, 62 percent (range, 25-90 percent).

The matrix consists of various proportions of microcrystalline silica, microgranular silica, chert, muscovite and sericite. Some slides contain minute sericite flakes evenly scattered throughout, while some slides have no sericite. Small masses of muscovite occur in a few slides. Incipient chlorite development is associated with the clay material in most slides.

Microcrystalline silica and microgranular silica form most of the matrix in all of the slides; there is a large variation in the proportion of each silica type. Chert constitutes a small percentage of the matrix in 6 slides, all of which are from the upper part of the unit. The silica acts as the cement and accounts for the hardness and chertlike character of the siltstone. The matrix cement of the 3 slides from the central hematite-rich zone is made up of a solid mass of iron in which detrital grains are floating.

The lower part of the formation contains some carbonaceous material concentrated along bedding planes. This material is associated mainly with the cross-lamination structures and contributes the dark coloration to these structures.

### *Sedimentology*

Epstein and Epstein (1967, p. 18) and Willard (1939, p. 154) suggest that a period of emergence followed deposition of the Ridgeley sandstones. In the mapped area this episode is presumably represented by the white clay at the base of the Schoharie-Esopus. This writer (Sevon) has seen no positive evidence to support or disprove subaerial exposure. If such exposure occurred, then the transition from subaerial clay (base) to marine (remainder) in the Schoharie-Esopus took place without the preservation of any transgressive marginal marine environments. The key to this transition lies, in part, in interpretation of the abundant cross-lamination structures occurring in the lower part of the formation.

These structures are identified as horizontal burrows, *Taonurus,* by Epstein and Epstein (1969, p. 157; Figure 21, p. 159). Seilacher (1967, p. 417) refers to *Zoophycos* communities in the Esopus of the Appalachian system, presumably meaning these structures. However, the description of the *Zoophycos* facies given by Seilacher (1964, Table 1, p. 310-311) suggests that these structures are not *Zoophycos,* and the general depth connotation of the *Zoophycos* facies (Seilacher, 1967, p. 417) would require transition through shallower marine environments without preservation of deposits from those environments. Likewise, the description of *Zoophycos* given by Hantzschel (1962, Figure 137, p. W219, p. W220) bears little similarity to the description of these structures.

This writer (Sevon) proposes that these structures represent remains of small ripples formed by tidal or wave-generated currents which varied in direction of movement. The carbonaceous material which defines the structures seems particularly abundant and may indicate a nearby source such as a salt marsh (Odum and de la Cruz, 1967). The plentiful particulate organic matter trapped between thin-sediment ripple laminae apparently added sufficient cohesion to the ripples to allow overturning of some laminae by later currents. Layers which have been scoured without overturning presumably were affected by stronger currents. The thinness of individual beds and the scarcity of marine fauna suggest that the detritus supply was small and that the environment was either too agitated or received too much sediment, or both, to promote good faunal development.

The hematite-rich bed near the middle of the formation represents oxidation-reduction (Eh) and alkalinity-acidity (pH) conditions conducive to iron accumulation. Such conditions may represent partial or periodic subaerial exposure, but the beds are sufficiently noninformative that definite conclusions are currently lacking.

The remainder of the Schoharie-Esopus Formation shows an upward decrease to total absence of the cross-lamination structures and an increase in marine fauna, mainly brachiopods.

The writer (Sevon) suggests that, following the presumed subaerial exposure represented by the basal clay, the mapped area gradually subsided while receiving a very small detrital input. A shallow marginal marine area developed which was generally submerged, but subject to tidal and wave-generated currents. During the accumulation of the iron-rich sediment, periodic exposure on a tidal flat resulted from slowed subsidence or transgression. Following the tidal-flat episode, shallow-water conditions were restored and followed by gradual deepening of the water to a point where current activity was insufficient to create ripples; fauna characteristic of a deeper water environment developed. The end of Schoharie-Esopus deposition was marked by shallowing water and initiation of Palmerton sandstone deposition.

## Palmerton Formation

The Palmerton Formation is a massive, white, variably indurated, coarse- to fine-grained sandstone which crops out almost continuously along the crest of Stony Ridge in the southern part of the area. The sandstone often forms the crest of Stony Ridge as a narrow wall of rock projecting 30 to 50 feet above the surrounding topography. The unit is well displayed in outcrops along the crest of Stony Ridge; in roadcuts at Little Gap, West Bowmans (measured section 5), and Lizard Creek Junction; and in quarries at Palmerton and Germans.

Massiveness, lack of definite bedding planes and complete domination by joints are characteristic features of the unit (Figure 85). Bedding is rarely defined by aligned pebbles, and planes defined by a few brachiopod valve molds were observed in the exposure on the Northeast Extension of the Pennsylvania Turnpike near Lizard Creek Junction. The uniformity of composition and grain size throughout the unit and the

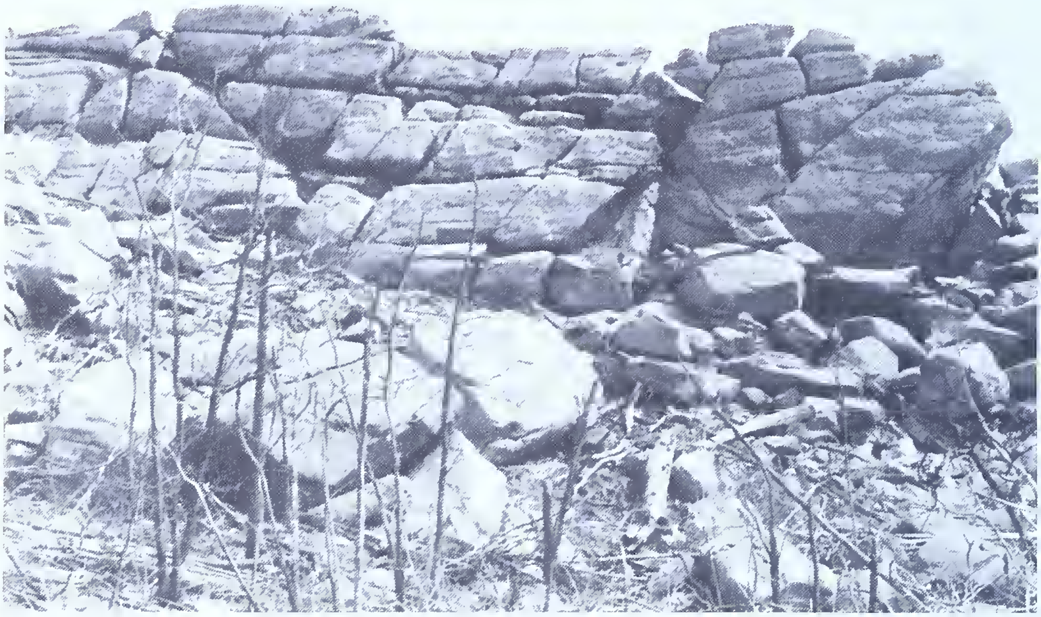


Figure 85. Typical outcrop of massive Palmerton sandstone in which joints are prominent. Large face is a north-facing and -dipping bedding plane. Outcrop is about one-half mile northeast of Aquashicola.

gradational nature of grain-size changes contribute to the lack of bedding-parallel partings.

The bulk of the sandstone is made up of quartz grains ranging from 0.062 to 2.0 mm in diameter. The sandstone usually has a small percentage of grains larger than sand size, generally less than 1/4 inch in diameter and rarely larger than 1/2 inch in diameter. Figure 86 shows the grain-size distribution in 10 samples of the Palmerton. The analyses indicate that the Palmerton is generally well sorted and has a unimodal grain-size distribution with an abundance of grains in the range between 1 and 2 mm in diameter. Further grain-size information is presented in the section on microscopic characteristics. In hand specimen the individual sand grains are generally angular to subrounded, whereas the pebbles are rounded.

The quartz richness of the Palmerton is indicated by the chemical analyses in Table 6 and the thin-section analyses (see "Microscopic Characteristics"). The amount of clay in the Palmerton is generally very small, and field observation suggests that it occurs mainly in the upper part of the unit. The mineralogic purity of this unit is the main reason for the white to light-gray color of the formation. This coloration dominates the unit except for those parts discolored by hematite.

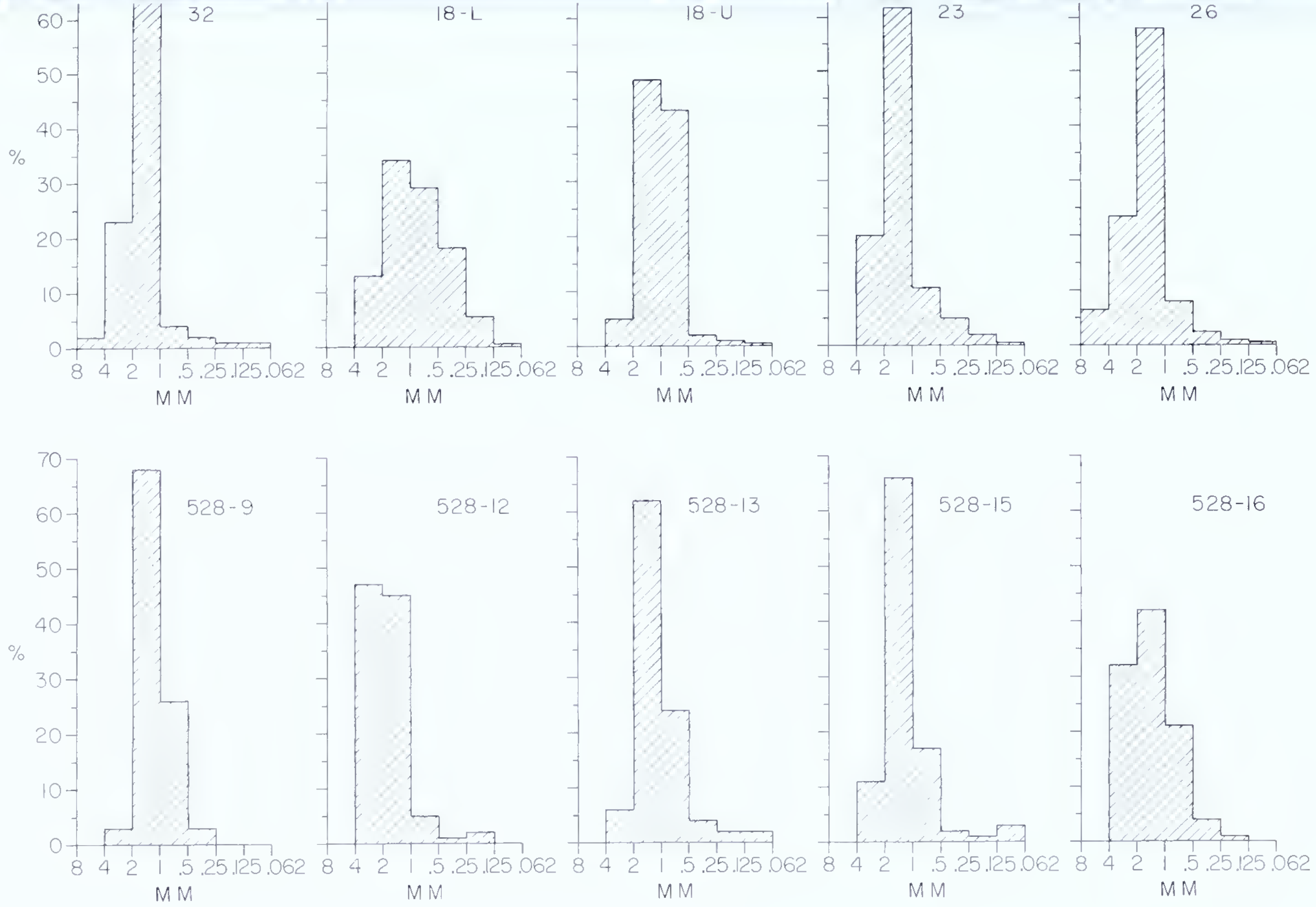


Figure 86. Histograms of grain-size distribution in 10 samples of the Palmerton Formation. Data for the upper 5 histograms are from standard sieve analyses of naturally disaggregated sandstone. Data for the lower set of histograms are from thin-section size analyses. Numbers above each histogram are sample identification numbers.

Table 6. *Chemical Analyses of Two Samples of the Palmerton Formation from Little Gap*

(Analyses furnished by North American Refractories Company, Little Gap)

| | Sample | |
|---|---|---|
| Component | A | B |
| $SiO_2$ | 98.75% | 98.64% |
| $Al_2O_3$ | .12 | .23 |
| $TiO_2$ | .02 | .02 |
| $Fe_2O_3$ | .73 | .79 |
| CaO | Trace | Trace |
| MgO | Trace | Trace |
| $Na_2O$ | .02 | .02 |
| $K_2O$ | .02 | .01 |
| Ignition loss | .34 | .29 |

Hematite occurs as an accessory mineral in the Palmerton Formation between Little Gap and Lizard Creek (Plate 1). This occurrence corresponds to the areal distribution of the Hazard paint ore found in the overlying Buttermilk Falls Limestone. The iron was presumably leached from the paint ore and deposited in the sandstone by percolating solutions; it occurs as scattered interstitial concentrations, as concentrations along stylolitic seams, and as rock cement (see "Microscopic Characteristics"). The hematite is found mainly in the lower part of the formation and is often associated with iron-rich bands which appear to have migrated into fresh rock from joints.

Variations in silica cementation make the induration of the Palmerton quite heterogeneous. Some sandstones have silica cementation at grain point contacts only, resulting in a rock which is generally weak and disaggregates readily (Figure 87). The pores of such rock may be empty or filled with clay. In some cases the pores are filled with hematite which acts as an excellent cement and retards rapid disintegration.

In areas where silica has been extremely mobile, the Palmerton Formation often has a quartzitic texture (see "Microscopic Characteristics"). Original grain boundaries have been destroyed by grain interpenetration and silica overgrowths, and original pore space has been filled with overgrowths and other secondary silica. This sandstone is very resistant to disintegration and sometimes forms talus blocks such as shown in Figure 88.

The variation in silica cementation is not predictable. Quarry operators find that induration often varies considerably within a few hundred or even a few tens of feet. The zone of most intense cementation and induration corresponds to the area containing hematite in the sandstone, that part of Stony Ridge between Little Gap and Lizard Creek. To the northeast and southwest of this zone, Stony Ridge is much less well

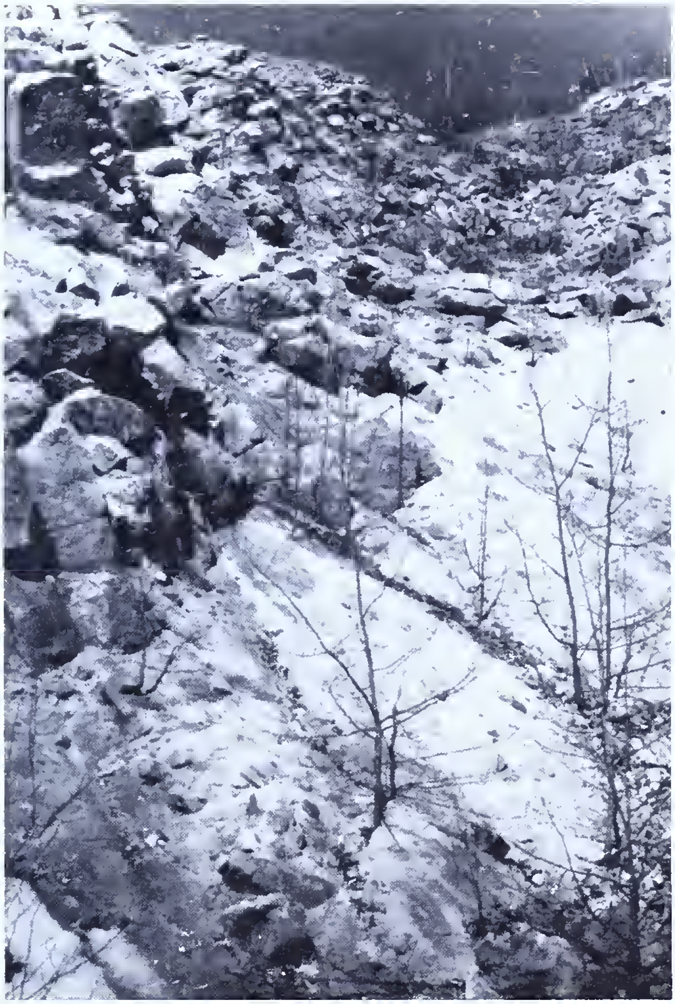


Figure 87. Talus of sand resulting from natural disintegration of poorly cemented Palmerton sandstone in a Refractories Sand Company quarry at Andreas, southwest of Lehighton quadrangle boundary.

developed, presumably because of a lack of silica cementation in the sandstone.

The Palmerton Formation is sparsely fossiliferous. A few single-valve brachiopod molds were observed in the unit at West Bowmans (measured section 5, unit 47) and at Little Gap. A few silicified horn corals have been found in the lower part of the formation in the quarries at Little Gap.

The thickness of the unit is about 100 feet throughout the area. Outcrops at Andreas (2½ miles southwest of Germans) suggest that the formation may be thinning to the southwest (Sevon, 1968a).

The lower contact of the Palmerton Formation with the underlying Schoharie-Esopus Formation is placed at the base of the lowermost sand-

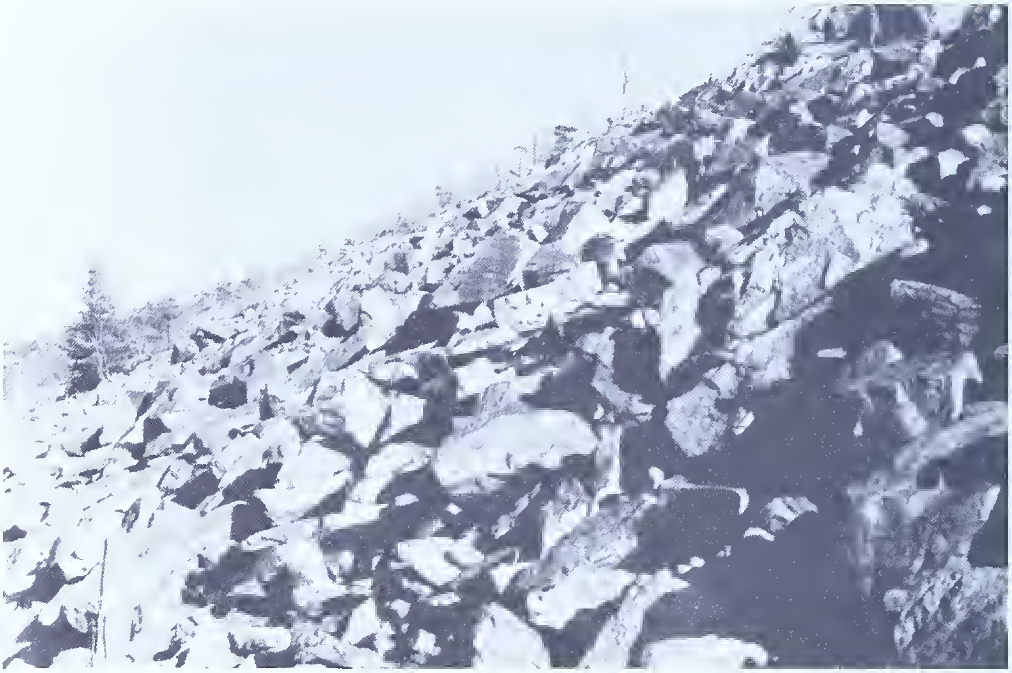


Figure 88. Talus of quartzitic blocks resulting from natural disintegration of Palmerton sandstone south of Bowmanstown.

stone interbed in a series of four or more sandstone and siltstone interbeds which range from 1 inch to 3 feet in thickness. These interbeds have sharp boundaries, but often lack parting planes at the textural boundaries as a result of a high degree of silicification. A few floating quartz grains occur in the siltstone interbeds and the sandstone interbeds have a higher percent of fine-grained matrix than the overlying sandstones. This interbed zone is best exposed at West Bowmans (measured section 5, units 35-38) and is not more than 4 feet thick in any observed exposure.

The upper contact of the Palmerton is sharp and marked by a change in lithology from sandstone to clay. This contact is exposed in the mapped area only at West Bowmans (measured section 5, units 7 and 8). The uppermost 1 to 2 feet of the Palmerton sandstone becomes increasingly friable and contains varying amounts of black, dead petroleum or tar. This black material occurs as coatings on individual quartz grains and tends to be concentrated in small isolated masses or discontinuous zones up to 1 foot thick. The change to the overlying clay is abrupt and it is this weak clay that weathers rapidly, creating a steep wall of rock when the Palmerton dips vertically or nearly vertically, a normal condition for the unit in the mapped area.

*Microscopic Characteristics*

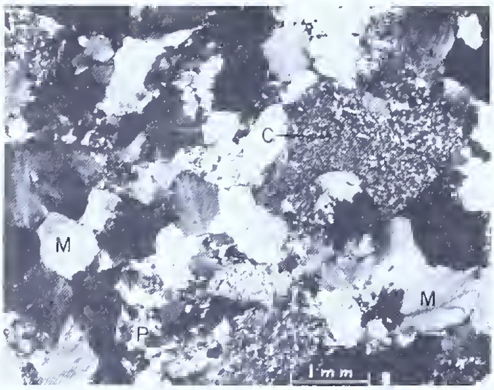
Twenty-five thin sections of Palmerton sandstones from 6 different localities were examined. A point-count composition analysis was performed on 8 slides, and a thin-section size analysis was performed on 7 of the same slides.

The Palmerton Formation is composed almost exclusively of silica, dominantly in the form of quartz. The following average composition seems to be typical of Palmerton sandstone having a very coarse (1-2 mm) grain-size mode:

| | |
|---|---|
| Detrital fraction: | |
| Highly strained polycrystalline quartz | 47% |
| Highly strained monocrystalline quartz | 26% |
| Microcrystalline silica grains | 3% |
| Siliceous rock fragments | 3% |
| Slightly strained monocrystalline quartz | 1% |
| Unstrained monocrystalline quartz | 1% |
| Heavy minerals | Trace |
| Matrix: | |
| Secondary quartz overgrowths and interstitial filling | 10% |
| Hematite and limonite | 5% |
| Microcrystalline silica | 4% |
| Sericite | Trace |
| Total | 100% |

Point-count analysis of 8 slides and visual estimation of 14 slides indicate that as the grain-size mode decreases, the amount of polycrystalline quartz decreases and that Palmerton sandstones with medium (0.25-0.5 mm) grain-size modes have 2 to 3 times as much monocrystalline quartz as polycrystalline quartz. Rock fragments are siltstones and the only heavy mineral noted was epidote. Some quartz grains have a "wormy" appearance and apparently have minute inclusions of a bluish (and sometimes reddish) mineral which may be chlorite. Although constituting only a fraction of a percent, these grains occurred in every slide examined.

The sandstones are bound together mainly by secondary silica which occurs both as overgrowths of quartz grains and interstitial filling. Solution activity has been intense in much of the unit and most grains are modified. Most of the quartz grains were originally well rounded, but have secondary overgrowths which impart the angularity seen in hand specimen. Suturing of grain contacts has been intense in some slides and minimal in others. Figure 89 shows the typical sandstone components as well as some stylolites resulting from intense solution activity, and Figure 90 shows another sandstone with iron cement and minimal solution. Hematite acts as cement in some of the Palmerton and generally occurs only in the interstices between grains, although it sometimes occurs along sutured contacts. Microcrystalline silica occurs as matrix



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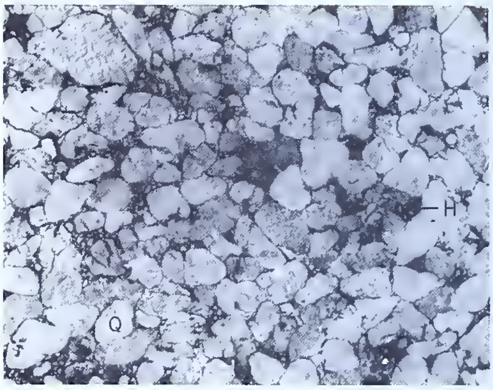

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Figure 89. Thin section of Palmerton sandstone showing typical detrital components, sutured contacts and stylolites with hematite concentration. Sample is from West Bowmans. C, chert; M, monocrystalline quartz; P, polycrystalline quartz.

Figure 90. Thin section of Palmerton sandstone showing iron cement and quartz-grain point contacts. Sample is from West Bowmans. Q, quartz; H, hematite.

material only in sandstones in the interbedded Palmerton-Schoharie-Esopus contact zone. Clay is almost totally absent in the thin sections examined.

The average grain-size distribution of the Palmerton sandstone in the 7 thin sections used for grain-size analysis is:

| Grain Size | Percentage |
|---|---|
| Pebbles (2-8 mm) | 16% |
| Sand | |
| Very coarse (1-2 mm) | 64% |
| Coarse (0.5 - 1 mm) | 16% |
| Medium (0.25 - 0.5 mm) | 2% |
| Fine (0.125 - 0.25 mm) | Trace |
| Very fine (0.062 - 0.125 mm) | 1% |
| Silt | |
| Coarse (0.031 - 0.062 mm) | 1% |
| Total | 100% |

Fourteen of the thin sections examined had very coarse grain sand size modes, 7 had coarse-grain sand size modes, 3 had medium-grain sand size modes, and 1 had a very fine grain mode. In all of the slides examined the grain-size distribution was unimodal, lacking a wide spread of grain sizes and lacking fine-grained material (silt and clay).

### *Sedimentology*

The interbedded nature of the lower Palmerton sandstone contact indicates a transition from the marine environment of the underlying

Schoharie-Esopus into the presumed marginal marine environment of the Palmerton. The rare occurrence of brachiopod and coral fossils indicates at least a close proximity to marine conditions, while the mineralogical composition, original grain roundness and good size sorting indicate extreme reworking. The lack of defined sedimentary structures results partly from the mineralogical and textural uniformity and partly from the postdepositional silica mobility. The Palmerton sandstone probably accumulated in a nearshore or foreshore environment in response to temporary shallowing of water. To the east near Stroudsburg (30 miles), the Palmerton is missing, presumably by nondeposition, and the equivalent interval is part of the Buttermilk Falls Limestone (Epstein and Epstein, 1967, Figure 5, p. 17). To the west, the exact relation of the Palmerton to adjacent units becomes less clear (Sevon, 1968a), and the sedimentology of the unit undetermined.

## Buttermilk Falls Limestone

The Buttermilk Falls Limestone in the mapped area consists of a deeply leached interval of limestones and shales which occurs between the top of the Palmerton Formation and the base of the Marcellus Formation. The unit has an apparent maximum thickness of 40 feet, but is known only from three exposures and is not a mappable unit although it is a distinctive lithology. For mapping purposes the unit has been combined with the Marcellus Formation and the base of the combined units is placed at the top of the Palmerton Formation.

The only complete exposure of the Buttermilk Falls Limestone in the mapped area occurs at West Bowmans (measured section 6, units 8-94). A partial exposure of the formation occurs behind a garage at Little Gap and a very small exposure of the formation existed in 1966 in a sandstone quarry at Germans. Several references treat the subsurface occurrence of the unit (see sections on mineral resources and paint ore).

The Buttermilk Falls Limestone is a heterogeneous sequence in the mapped area and is subdivided into three informal members: a lower shale member, the Hazard paint ore member, and the upper limestone member. These units are discussed separately.

### *Lower Shale Member*

The lower shale member is known only from the exposure at West Bowmans (measured section 6, units 8-27) where the unit is less than 5 feet thick. Fresh rock for this whole interval is probably dark-gray (N3) to grayish-black (N2), massive, structureless clay shale which develops fissility upon weathering, but extreme weathering of the outcrop has reduced almost all of the shale to clay. The clay occurs in numerous thin beds with brown and red coloration and various degrees of iron cementation. Several thin clay beds are well indurated by iron cement, but most of the clay is soft and develops some fissility during disintegration.

Some very intensely weathered Buttermilk Falls has been exposed by quarrying operations in the western part of the Alliance Sand Company quarry at Aquashicola. This material is nearly white and very claylike in character. Semiquantitative X-ray diffraction analyses (by Pennsylvania Geological Survey) of two samples of this material gave the following results:

| | A | B |
|---|---|---|
| Mica | 49% | 32% |
| C - V - Mo | 1 | 4 |
| K | 12 | 16 |
| Feldspar | 1 | Trace |
| Quartz | 39 | 48 |
| Total | 100% | 100% |

The lowermost 5 inches of the member contains coarse-grained rounded quartz grains floating in the weathered clay. The percentage of grains decreases upwards from the base (measured section 6, units 8-10). The actual basal contact, however, is sharp with the underlying massive sandstone. The upper contact with the overlying Hazard paint ore member is gradational over a short interval.

The lower shale member of the Buttermilk Falls Limestone may correspond to the Needmore shale of the Susquehanna River area, but no physical correlation with that unit has been attempted.

### *Hazard Paint Ore Member*

The Hazard paint ore member of the Buttermilk Falls Limestone is a hard clay ironstone. The ironstone has a bluish metallic color when fresh, but weathers readily to grayish red (5R4/2). At West Bowmans (measured section 6, units 28-30) the unit consists of two ironstone beds, one 7 inches thick and the other 5½ inches thick, with an intervening black massive clay shale which is 6½ inches thick (total thickness of the member is 19 inches). Descriptions of this member in the literature (see section on paint ore in "Mineral Resources") indicate a maximum thickness of 4 feet in the area around Hazard and Palmerton. Although no fossils occur in the unit at West Bowmans, some brachiopod valves were seen in float material from this interval, and Willard and Whitcomb (1938) reported a moderate fauna from the unit.

Although this member is exposed only at West Bowmans, the areal distribution of the paint ore within the mapped area is readily inferred from the distribution of pits made during former mining operations and from the literature. The Hazard paint ore member apparently does not occur east of Little Gap nor west of the intersection of Stony Ridge and Lizard Creek. The relationship between the Hazard paint ore and the iron staining in the Palmerton Formation has already been discussed and appears to support this areal distribution.

### *Limestone Member*

The remainder of the Buttermilk Falls Limestone is a limestone member with lithologic similarity to, and known stratigraphic correlation with, rocks of the Buttermilk Falls Limestone near Stroudsburg, Pennsylvania, 25 miles to the northeast. This member is completely exposed at West Bowmans (measured section 6, units 31-94) and is 34 feet thick. The uppermost 10 feet is exposed at Little Gap and about 5 feet of the central part of the unit was exposed in a sandstone quarry at Germans in 1966.

Since almost all of the exposed limestone member is deeply weathered and extensively leached, only general statements can be made about the unweathered rock of the member. The fresh rock indicates that the bulk of the unit in the mapped area consists of finely to coarsely crystalline, fossiliferous, massive, hard, clayey to silty, medium-gray (N5) to dark-gray (N3) limestone interbedded with black chert. Some black chert occurs as nodules or discontinuous bands within limestone beds, but most occurs as discrete beds. Fossils occur throughout the member, sometimes scattered sparsely through a bed and sometimes in abundant concentrations. The fossils are siliceous in fresh and partially weathered rock, but in deeply leached rock the siliceous material has been leached, leaving only molds of the fossils. Brachiopods, corals, crinoid columnals, and trilobites are the commonly observed fossils.

Almost 25 feet below the top of the Buttermilk Falls Limestone at West Bowmans is the base of a 1-foot-thick zone of micaceous clay (measured section 6, units 61-63). The size of the mica flakes appears to decrease from medium-grained-sand size at the base to very fine grained sand size at the top. There also appears to be a gradual upward decrease in the amount of mica from very abundant at the base to very sparse at the top. This mica may be associated with the Tioga bentonite which occurs in the overlying Marcellus Formation.

Weathering of the limestone member has been intensive; most of the original limestone has been completely leached, leaving behind beds of clay and fine-grained siltstone of various yellowish-brown colors. The clay is usually soft and sometimes shows a slight fissility. The siltstones generally have a high porosity as a result of leaching of the calcite cement, but they retain some cohesion and have a pithy character.

Surface float from this unit is virtually nonexistent. A few pieces of black chert occur in some relatively undisturbed areas, but, for the most part, mining pits and Palmerton sandstone float obscure any trace of Buttermilk Falls float.

The upper contact of the Buttermilk Falls Limestone is sharp with the overlying Marcellus Formation and is marked by an abrupt change from limestone to black shale (measured section 6, units 94-95). This contact is not detectable in most places.

### *Microscopic Characteristics*

Three thin sections were prepared from samples collected on the west side of the Turnpike roadcut at West Bowmans. One sample came from the Hazard paint ore member and two samples came from the limestone member.

The Hazard paint ore sample is predominantly siderite with less than 25 percent microcrystalline silica, sericite, and pyrite. Most of the siderite occurs as microcrystalline aggregate moderately stained by iron alteration. Some of the siderite occurs as clear silt-sized grains replacing original shell material. The microcrystalline silica occurs in thin, elongate, discontinuous masses surrounded by iron-stained siderite. The pyrite occurs as scattered clay-sized grains and as replacement of original shell material. A very small amount of sericite is associated with the microcrystalline silica.

One of the limestone thin sections is composed entirely of uniform microcrystalline calcite and fossil fragments. Rare phosphatic shell pieces were noted, but most of the shell material is composed of microcrystalline calcite. Most of the fragments are medium-grained sand size or smaller.

The other thin section contains over 95 percent microcrystalline silica with some iron staining. A small percentage of fine- to medium-grained silt-sized quartz grains is scattered throughout the slide, as are a few sericite flakes.

### *Sedimentology*

The deeply weathered clay at the base of the Buttermilk Falls Limestone is reminiscent of the similar interval at the base of the Schoharie-Esopus Formation, and suggests the possibility of emergence following deposition of the Palmerton. However, this writer (Sevon) found no positive evidence for or against such an emergence. The overlying shaly interval presumably represents sediments accumulated during marine submergence, but real evidence is lacking. The Hazard paint ore is characterized by a diverse and abundant marine fauna (Willard and Whitcomb, 1938), abundant iron carbonate, some silica, and a lack of detrital material. Siderite formation occurs best when pH (acidity-alkalinity) is between 7 and 7.8 and when Eh (oxidation-reduction potential) is between 0 and −0.2 (Krumbein and Garrels, 1952, Figure 8, p. 26).

Whether the iron carbonate is primary or secondary in origin is not known at present, but the faunal characteristics discussed by Willard and Whitcomb (1938) suggest that the environment was somewhat different from environments of the same stratigraphic interval elsewhere. This writer (Sevon) suggests that a localized area of physical and chemical conditions appropriate for iron carbonate development, in which a marine fauna flourished, existed briefly in the mapped area. Almost no detritus came into the area, and available silica and iron was concentrated from the sea water either as a primary deposit or as a diagenetic product soon after initial deposition. The remainder of the Buttermilk Falls Limestone presumably represents only slightly changed conditions in which more detritus came into the area and physical-chemical conditions were not suitable for iron concentration. The occurrence of limestone and bedded cherts may indicate only a slight shift of pH to 7.8 or higher. If the micaceous clay in the upper part of the formation is related to the Tioga bentonite, then it represents a volcanic ash fall (Dennison and Textoris, 1966).

## Marcellus Formation

The Marcellus Formation is a sequence of grayish-black (N2), fissile clay shale which occurs only rarely in natural exposures in the mapped area. The rock is well exposed in several man-made outcrops: the Northeast Extension of the Pennsylvania Turnpike at West Bowmans, around the Alliance Sand Company quarry north of Palmerton, along the east side of the abandoned Lehigh Canal north of North Weissport, in a roadcut just south of Little Gap, and along a secondary road between Aquashicola and Christian Corner. Poorer exposures occur rarely in streams.

These shales are composed dominantly of clay, but some very thin (less than 1 foot thick) fine- to medium-grained siltstone beds occur randomly within the unit. A zone of mixed calcareous shale and limestone occurs about 27 feet above the base of the unit in the Turnpike exposure. The thickness of the calcareous zone is apparently variable, because it is 16 feet thick on the east side of the Turnpike exposure and 38 feet thick on the west side of the same exposure. The calcareous rocks weather in outcrop to a slightly grayer color than adjacent shale. Although this zone has not been identified elsewhere (perhaps because of the lack of outcrop), a number of tear-drop-shaped, calcareous concretions averaging 6 inches in diameter and 12 inches in length (maximum: 12 inches in diameter and 24 inches long) occur in the same stratigraphic position at the Alliance Sand Company quarry exposures north of Palmerton. Another calcareous unit may be present in the upper third of the Marcellus, but it is known only at the Turnpike exposure, where some calcareous concretions, 1 to 2 feet in diameter, occur aligned parallel to bedding about 400 feet above the base of the unit.

Within the basal 17 inches of the Marcellus Formation exposed along the Turnpike at West Bowmans are three thin layers (measured section 6, units 100, 102 and 104) tentatively identified as the Tioga bentonite by Dennison (1966, personal commun.). These layers are composed of dark-gray (N4) clay shale with abundant amounts of medium- to coarse-grained mica flakes and pyrite nodules up to 1 mm in diameter. The mica gives the layers a silvery appearance, particularly in the lower two layers which contain more mica (50 to 75 percent of the layer) than the upper layer (10 to 20 percent of the layer). Each bentonite layer is immediately underlain by a thin blackish-red (5R2/2) ironstone layer. The presence of the Tioga bentonite in the same relative stratigraphic position at Little Gap is suspected from float material (Dennison, 1966, personal commun.).

The fissility of the Marcellus shales is well developed and seems to be variably related to cleavage and bedding. The fissility parallels bedding in the lower part of the unit and apparently in some of the upper part. Bedding is sometimes detectable by the presence of organic material oriented along fissility planes. However, in much of the unit the relation of fissility to bedding and cleavage is obscure and in some intervals the fissility may parallel cleavage. The fissility causes the Marcellus to disintegrate into paper-thin platelets which produce a characteristic brittle crunching sound underfoot.

The Marcellus generally disintegrates into a clayey soil with only a small amount of float material occurring at the surface. Weathering of the shale causes little or no change in the color, except in extreme weathering, when the color changes to light gray (N7) or very light gray (N8). The platelets are often coated with iron stain which varies from light brown (5YR5/6) to moderate brown (5YR4/4) to moderate-yellowish brown (10YR5/4) and yellowish gray (5Y7/2). Occasionally moderate-reddish-brown (10R4/6) and dark-reddish-brown (10R3/4) iron stains are present.

The Marcellus Formation in this area is not abundantly fossiliferous, but at least the lower part of the unit contains some fossils. All of the fossils noted occur as impressions or remains oriented on fissility planes and are small brachiopods, pelecypods and light-brown (5YR5/6) organic(?) fragments. Part of a large (estimated length exceeds 4 inches) trilobite of indeterminable order was collected from the Lehigh Canal exposure north of North Weissport.

The lower contact of the Marcellus shale with the underlying Buttermilk Falls Limestone is sharp at West Bowmans (measured section 6, units 94-95). Wietrzychowski (1964) found a similar sharp contact at

Little Gap by trenching. Along the Turnpike the lithology changes from alternating light-colored siltstones and clays below to black clay shale above. The upper contact is gradational over a distance of 25 to 100 feet from clay shale below to silty shale above, accompanied by a subtle change in the weathering characteristics of the different lithologies. The Marcellus clay shale disintegrates into paper-thin platelets with little or no color change, while the overlying Mahantango shales break down into thicker and more irregularly shaped pieces with a color change to lighter shades of gray. This gradation is exposed at West Bowmans, but is generally difficult to detect elsewhere.

Because of the gradational nature of the upper contact and the structural complexity of the only complete exposure of the unit (see section on structural geology), no exact thickness can be determined for the Marcellus Formation in the mapped area. However, if it is assumed that little or no thickening has occurred in the Turnpike exposure, then a thickness between 750 and 800 feet may be assigned to the unit.

For the purpose of mapping in the Lehighton and Palmerton quadrangles, the Marcellus Formation and Buttermilk Falls Limestone have been combined and mapped as one unit. The upper contact of the underlying Palmerton sandstone was used as a convenient lower mapping boundary. The upper contact of the Marcellus with the overlying Mahantango is rarely detectable in the mapped area because of its gradational nature and because of the alluvial and colluvial cover (Plate 1) which often overlies the transition zone. Thus the mapped boundary between the Marcellus and the Mahantango is somewhat subjective.

The Marcellus shale exposed in the center of the Lehighton anticline (Plate 1) has not been previously reported from that area. The exposed shale appears to be the same as that occurring in the southern part of the area.

### *Microscopic Characteristics*

Thirteen thin sections of the Marcellus Formation were examined. Eleven of the samples were collected at intervals (average, 90 feet; range, 10-255 feet) on the west side of the Turnpike roadcut at West Bowmans. The other two samples came from the Alliance Sand Company quarry north of Palmerton.

The bulk of the Marcellus (9 slides) comprises a mass of black, homogeneous organic material which obscures a matrix of predominantly microcrystalline silica mixed with minute sericite flakes. The organic material is both disseminated throughout the rock and concentrated in planes parallel to bedding. Sericite is the predominant mineral in 2 slides and is aligned parallel to bedding with a resultant "rock extinction" under crossed nicols. Seven of these slides contain a small amount of clay-sized nodules and/or euhedral grains of pyrite. The quantity of pyrite decreases upward through the formation and in the 2 uppermost samples pyrite is not present. In both of these uppermost samples there is, however, a small quantity of clay-sized magnetite-ilmenite particles.

About 1 percent of each slide is very fine to fine-grained silt-sized quartz grains which are scattered throughout the slide. Rare medium-grained silt-sized muscovite flakes also occur.

Three of the slides were from the calcareous zone in the lower Marcellus and show it to be a mixture of predominantly coarse microcrystalline calcite, small amounts of fine- to medium-grained silt-sized quartz grains, pyrite, disseminated black organic material, and fossil fragments. The fossils are mainly brachiopod shells and some crinoid stems which have been replaced by sparitic calcite. The fossil fragments are generally sand sized or smaller. The pyrite constitutes up to 5 percent of the slide and occurs as clay-sized anhedral and euhedral grains as well as amorphous silt-sized masses.

### *Sedimentology*

The origin of black shales has been much debated and excellent discussions are given by Rich (1951), Pettijohn (1957, p. 361-363; 622-626), Dunbar and Rodgers (1957, p. 202-208), and Conant and Swanson (1961). The highly carbonaceous and pyritic Marcellus Formation was probably formed in poorly aerated deep water which resulted from continued subsidence and lack of detrital input in the mapped area and in the larger area of Marcellus occurrence. Such poorly aerated conditions are produced by a lack of circulation and result in increased pH (acidity-alkalinity) and decreased Eh (oxidation-reduction potential). The organic material-pyrite association indicates an Eh of −0.25 or lower and a pH of 7.0 or higher. The calcareous zone near the base of the formation and the calcareous concretions in the upper part of the unit presumably indicate a slightly higher Eh and a pH of 7.8 or higher (Krumbein and Garrels, 1952, p. 26). The more abundant fauna in the lower calcareous zone indicates somewhat more aerated conditions, whereas the sparse fauna in the remainder of the shale indicates poor aeration. No comment can be offered regarding the reason for the poor circulation on the basis of observations in the mapped area. The stratigraphic context of the shale, the lack of detritus in the unit, and the lack of any sedimentary structures argue well for a deep-water origin in which poor circulation allowed the development of anaerobic conditions, accumulation of abundant organic material, and production of pyrite. Deposition of this black shale was terminated by increased circulation and detrital input associated with Mahantango sedimentation.

## Mahantango Formation

The Mahantango Formation in the mapped area includes between 2,100 and 2,400 feet of silty shales, and contains four fossiliferous zones and a siltstone zone.

Small outcrops of the Mahantango Formation are common, but continuous exposures are rare. South of the Weir Mountain syncline, the most complete exposures occur along the Lehigh Valley Railroad north of West Bowmans on the west side of the Lehigh River, along the approach ramp to Pa. Route 248 north of Bowmanstown on the east side of the Lehigh River, along a secondary road going west from the town of Little Gap toward Christian Corner, and along the first road to the north which joins this road. In Pohopoco and Mahoning Creek valleys good exposures occur along U.S. Route 209 in Lehighton, along the old Lehigh Canal at North Weissport (measured section 7), along the Lehigh Valley Railroad through Lehighton, and along the banks of Pine Run.

The Mahantango is medium-dark gray (N4) to dark gray (N3) when fresh and weathers to a variety of lighter gray and olive-gray hues. Light-olive gray (5Y6/1) and brownish gray (5YR4/1) are typical weathered colors, but much of the weathered shale has been tinted by iron staining and is pale-yellowish brown (10YR6/2), yellowish gray (5Y7/2) (probably most typical), light brown (5YR5/6) and dark-yellowish orange (10YR6/6). Weathered Mahantango shale in the area east of the Lehigh River and north of Pohopoco Creek is often grayish orange (10YR7/4). This coloration results from staining by materials leached from Illinoian(?) glacial drift which formerly covered the rock, but which has now been eroded in much of the area.

The Mahantango in the mapped area is basically a massive, nonbedded, silty shale. The shale has a graininess, apparently related to the amount of microcrystalline silica in the rock, which sometimes creates a false impression that the Mahantango is a siltstone. Bedding is often obscure in outcrops on the south limbs of synclines in the area where parting in the shale is controlled by cleavage (Figure 91), but is sometimes indicated by thin (1 to 2 mm thick) brownish siltstone layers. Rarely, bedding is indicated by an alignment of small (½ to 2 inches in diameter) calcareous or noncalcareous nodular concretions.

The mineralogic and chemical composition of samples of the Mahantango shale is presented in Table 7.

The Mahantango breaks down into plates whose shapes and sizes are controlled by cleavage, jointing, and poorly defined bedding-parallel partings. The Mahantango shales which occur on the south limb of the Weir Mountain syncline and on the north limb of the Lehighton anticline are highly jointed and have very prominent cleavage. The disin-

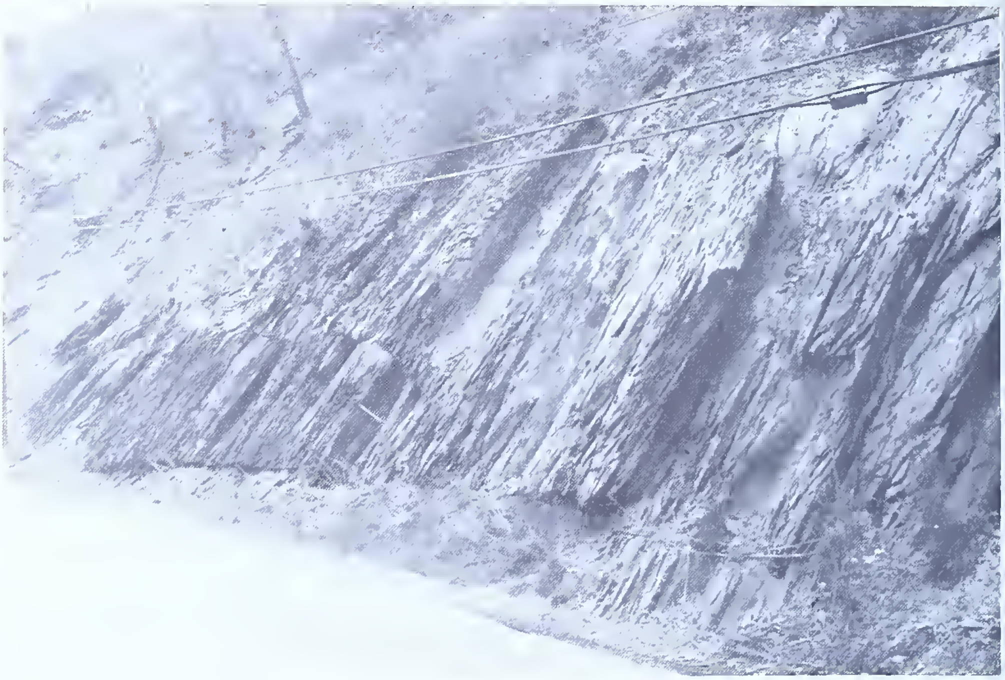
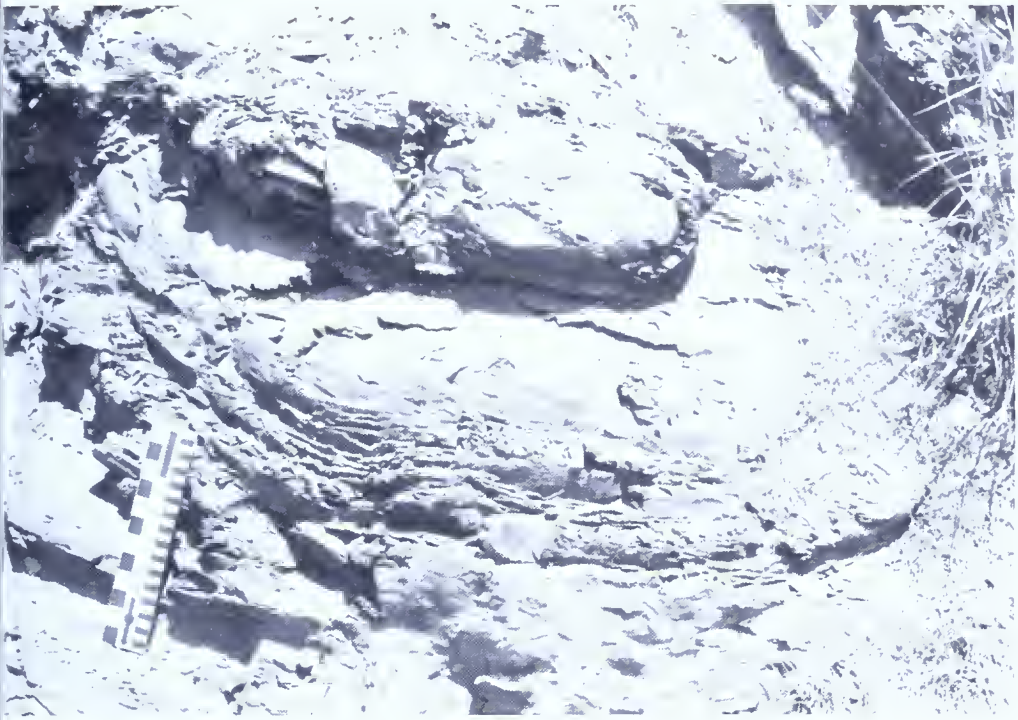


Figure 91. Outcrop of Mahantango shale with parting controlled by cleavage. The beds dip into the face of the outcrop (north). Outcrop is on north side of Fireline Road, Bowmanstown.

tegration pieces range from small chips 1 to 2 mm thick and a few millimeters long to large angular pieces 1 to 3 inches thick and up to 1 foot long. Long pencil-like fragments ¼ to ½ inch thick and several inches long are occasionally developed. Disintegration pieces in any given locality tend to be fairly uniform in size and shape. Breakdown where cleavage is not as well developed in the rock is less regular and usually results in moderate variation in size and shape of disintegration pieces. Breakdown of the shale into its component parts was not observed in the area, but presumably results in a mixture of clay and silt.

Ellipsoidal exfoliation-like structures up to 5 feet long with axes parallel to cleavage (Figure 92) are common to many Mahantango exposures on the south limbs of the synclines. These structures develop by mechanical disintegration along intersecting cleavage, bedding and fracture planes in the shales having prominent cleavage. These weathering structures in the Mahantango were misinterpreted as primary sedimentary structures by Willard (Willard and Cleaves, 1933, p. 763; Willard, 1957, p. 2302) and called "storm rollers."

Except for the fossiliferous zones described below, fossils are not common in the Mahantango Formation. Brachiopods, pelcypods, and gastropods occur rarely in isolated outcrops. These scattered fossils seem to occur mainly in the interval between the Centerfield fossil zone and the



igure 92. Ellipsoidal exfoliation developed by mechanical disintegration of Mahantango shale along cleavage, fracture, and bedding planes. Outcrop is along the north approach ramp to Pa. Route 248 north of Bowmanstown.

Nis Hollow siltstone. Bedding-plane concentrations of pelecypod valves sometimes occur a few feet to a few tens of feet below the base of the Nis Hollow siltstone.

The Mahantango Formation in the mapped area contains five mappable subunits of varying persistence: four fossiliferous units and a siltstone unit. Because of the thinness of these units, they are represented only as lines on the geologic map (Plate 1). They have proved useful in the delineation of local faulting. The fossiliferous units were discussed briefly by Sevon (1967b), but were not given names. Informal names are applied in this report for reasons of convenience and association.

### *Little Gap Fossil Zone*

The lowermost fossiliferous unit of the Mahantango Formation in the mapped area (referred to as "Lower fossiliferous member" in Sevon, 1967b) is herein informally named the Little Gap fossil zone after typical exposures just west of Little Gap along the road on the north side of Hunter Creek. The member occurs about 1,340 feet below the top of the formation in the area of Bowmanstown and about 1,530 feet below the top in the area of North Weissport.

The fossil zone is made up of medium-dark-gray (N4) to dark-gray (N3), calcareous and noncalcareous, silty fossiliferous shales. Fossils include brachiopod valves, horn and colonial corals, bryozoans, trilobites, and crinoid columnals. These fossils vary in abundance and position within the member and a complete ascending succession through the member is typically: 1) gradation from nonfossiliferous shale into silty shale containing a few scattered brachiopod valves; 2) concentrations of brachiopod valves and crinoid columnals on bedding planes; 3) structureless beds profuse with randomly oriented valves, crinoid columnals, horn corals, and bryozoans; and 4) rapid gradation within a few inches through a zone of scattered brachiopod valves and crinoid columnals into nonfossiliferous shale. The fossils in weathered exposures of this member usually occur as molds, but fresh rock exposed in stream beds often contains calcitic fossils.

Good exposures of the Little Gap fossil zone are not common, but the persistence of fossiliferous float from the unit makes the member readily mappable. The member is usually calcareous and tends to be slightly more resistant to mechanical disintegration than adjacent shales. As a result of this resistance, the member normally forms a slight topographic rise (1 to 3 feet) and sometimes has a noticeably different tonal quality on aerial photographs.

The Little Gap fossil zone has not been found west of the Lehigh River on the south side of the Weir Mountain syncline and does not appear to persist more than 5 miles west of the Lehigh River on the north side of the syncline. The zone is readily mappable northeast of the Lehigh River on both limbs of the Lehighton anticline and south of the Weir Mountain syncline. It thickens to the northeast, attaining a maximum known thickness of 40 feet at Kunkletown, and becomes a more prominent topographic feature northeast of the mapped area.

### *Kunkletown Fossil Zone*

The next higher subunit of the Mahantango Formation in the mapped area is another fossiliferous member (referred to as "Other fossiliferous member" in Sevon, 1967b), here informally designated the Kunkletown fossil zone after exposures occurring in the area of Kunkletown. This fossil zone is known in the mapped area only from float in the easternmost part of the area south of the Weir Mountain syncline. The following discussion of its character is based on exposures occurring to the east around Kunkletown.

The Kunkletown fossil zone occurs about halfway between the underlying Little Gap fossil zone and the overlying Centerfield fossil zone, but no distance below the top of the formation can presently be assigned to the unit. The fossil zone is characterized by the occurrence of fossils, mainly horn corals, in calcareous shales which are similar to adjacent noncalcareous shales. Within the mapped area the Kunkletown fossil zone is recognized only by the occurrence of float material, but to the east the member tends to form a topographic high as well as abundant float. The maximum known thickness of the member is 10 feet at Kunkletown, but the thickness is probably less in the mapped area. This zone is known to persist northeast of Kunkletown for at least 5 miles and presumably its disappearance in the mapped area represents the pinching out of a biofacies.

### *Centerfield Fossil Zone*

The third subunit of the Mahantango Formation in the mapped area is the Centerfield fossil zone (called "Middle fossiliferous member" in Sevon, 1967b). This fossil zone was correlated faunally with the Centerfield limestone of New York by Willard and others (1939, p. 178-179), and the name Centerfield is retained here for that reason. An outcrop of the fossil zone on the Turnpike at West Bowmans has been called the "Centerfield coral zone" by Willard (1957, p. 2302) and the unit is presumably the same as the "Centerfield coral zone" at the East Stroudsburg locality in east-central Monroe County (Willard, 1936a; Beerbower, 1957), but no physical correlation by lateral tracing has yet been accomplished. The base of the unit occurs about 835 feet below the formation top on the south side of the Weir Mountain syncline and about 668 feet below the formation top at North Weissport.

The fossil zone consists of medium-dark-gray (N4) to dark-gray (N3), calcareous (usually), silty shale. The zone contains brachiopod valves, bryozoans, horn corals, trilobites, pelecypods, cephalopods, and crinoid columnals. These fossils, particularly the brachiopod valves, often occur scattered throughout several tens of feet of vertical sequence, but generally the main bulk, particularly the corals, is concentrated in a zone 10 to 20 feet thick. Above this concentration the fossils are relatively rare. The fossil concentrations almost always occur in definite beds which are often interbedded with nonfossiliferous beds. The presence of some scoured bases, oriented single brachiopod valves and thin beds of barren shale intermixed with fossil concentrations suggests current activity and transported fossil material rather than a life assemblage. In fresh rock the fossils are calcitic, but in most exposures weathering has left only molds which sometimes show very delicate fossil structure.

The boundaries of the unit are gradational and the line placed on the map corresponds to the main part of the member which produces the largest amount of float material. Float from the fossil zone is generally abundant and the calcareous shales, which are slightly more resistant to mechanical breakdown than adjacent rocks, form a slight topographic rise (1-5 feet) in the mapped area and an even larger topographic expression east of the area.

The Centerfield fossil zone is about 18 feet thick at West Bowmans and about 40 feet thick at Lehighton, although the main fossil concentration at Lehighton occurs in the uppermost 10 feet of the zone. The fossil zone thins to the southwest and may not persist to the Schuylkill River, although float from the unit has been found as far as 5 miles southwest of the Lehigh River. The Centerfield fossil zone becomes more fossiliferous and apparently thicker northeast of the Lehigh River.

Except for the railroad-cut exposure north of West Bowmans and an exposure along U.S. Route 209 opposite the Lehighton-Weissport bridge, complete exposures of this unit are rare. Good partial exposures occur along Pohopoco Creek and along Buckwha Creek east of Little Gap.

### *Nis Hollow Siltstone*

The Nis Hollow siltstone is unique in that it is the only interval between the top of the Palmerton Formation and the base of the Towamensing Member of the Catskill Formation, about 4,500 feet of rock, which contains sand-sized material. The name is taken from Nis Hollow, which opens into the Lehigh River opposite the best exposure of the siltstone. This exposure occurs on the east side of the approach ramp to Pa. Route 248 north of Bowmanstown.

The Nis Hollow siltstone consists of a maximum of 56 feet of interbedded fine- to coarse-grained siltstones and very fine grained sandstones occurring in well-defined beds generally 2 to 6 inches thick. The siltstone beds almost always have sharp boundaries and are broken by regular and clean joint planes normal to bedding. These joints intersect at acute angles and often create very angular wedge-shaped float blocks. The fine-grained siltstones are medium-dark gray (N4) in color, whereas the coarse-grained siltstones and sandstones vary between medium gray (N5) and light-olive gray (5Y6/1). Most of the sandstones and coarse-grained siltstones are characterized by small pinpoint- to pin-head-sized light-brown (5YR5/6) spots on weathered surfaces. These spots are always scattered uniformly over the rock surface and range from 5 to 25 percent of the total surface area; they represent iron stain caused by weathering of iron particles in the coarser grained rocks.

Detailed examination of individual beds shows that many massive and apparently homogeneous beds are composed of numerous interbeds of varying grain sizes. These interbeds are often laterally discontinuous, have scoured bases, contain shale chips, and sometimes are graded. Animal burrow mottling is common and often disrupts interbeds. In some fine- to medium-grained siltstone beds the animal burrows are filled with coarser grained material and often have light-brown iron-stain spots.

Some parting planes have varying amounts of mica flakes oriented on the planes. Most boundaries between prominent beds are physical breaks between contrasting grain sizes, but some boundaries are coherent and do not readily separate.

Isolated brachiopod valves, pelecypods, and horn corals occasionally occur in this unit, particularly in the uppermost part.

Only three complete outcrops of the unit are known, one north of Bowmanstown along the approach ramp to Pa. Route 248, one in northwest Lehighton and one north of North Weissport (measured section 7, unit 28). Other outcrops are incomplete and often show only a few beds. The unit is readily mapped because of the distinctive float material and the prominent topographic expression (up to 20 or more feet above the adjacent shales) which results from the unit's greater resistance to erosion. The greater resistance to erosion is a consequence of (1) the well-bedded and massive nature of some of the beds, (2) the lack of prominent cleavage in the unit (which would create planes of weakness) and (3) the hardness of the coarser grained rocks.

The Nis Hollow siltstone appears to thin to the northeast of the Lehigh River and is not mappable east of the Lehigh River on the north limb of the Lehighton anticline, even though exposures in Pine Run (northeast corner of mapped area) indicate that traces of the lithology persist to that point. To the southwest of the mapped area, the unit apparently persists but is quite thin.

Although the siltstone occurs in the same relative stratigraphic position as the Montebello sandstone of the Susquehanna River area, no physical correlation by lateral tracing between the Nis Hollow siltstone and the Montebello sandstone has been attempted.

### *Tully Fossil Zone*

The uppermost subunit of the Mahantango Formation in the mapped area is the Tully fossil zone (referred to as "Upper fossiliferous member" in Sevon, 1967b). This member is named for an outcrop on the east side of the approach ramp to Pa. Route 248 north of Bowmanstown. Fossils from this outcrop have been correlated with typical Tully fauna elsewhere by Willard and others (1939, p. 225).

Willard (1935) defined the Tully as the base of the Upper Devonian and described an exposure of this unit, which he considered a formation, along the east bank of the Lehigh River where its fauna are typical of the Tully regionally (Willard, 1957, p. 2303). Heckel (1969, p. 10) compared the Tully in Pennsylvania with the type Tully in New York and confirmed this selection of the Tully horizon based on diagnostic fauna which included "echinoderm pieces, trilobites, auloporids and small horn corals, fenestellids, sulcoreteporid, rhomboporid, and fistuliporid bryozoans, and brachiopods including *Atrypa spinosa* Hall, small spiriferids, a terebratulid and *Douvillina*."

Fossils from this zone occurring along the limbs of the Lehighton anticline have been discussed by Skinner (1918) and Stevenson and Skinner (1919) and related to three different members. Mapping of the fossil zone has not demonstrated that three different horizons exist at this particular stratigraphic level, and the member names applied by Stevenson and Skinner (Weissport, Brodhead Creek, and Lehighton) are not used.

The unit is made up of medium-dark-gray (N4) to dark-gray (N3), calcareous to noncalcareous, fossiliferous silty shales. There appears to be no systematic distribution of different grain sizes or calcareous beds within the unit. The fossils are dominantly brachiopod valves and crinoid columnals with some horn corals and bryozoans. They are generally aligned along bedding planes or concentrated in thin calcareous beds which are interbedded with nonfossiliferous beds. The main concentration of fossils appears to be in the upper part of the fossil zone and very few fossils occur above this main bulk. Thin, very coarse grained siltstone beds up to 6 inches thick sometimes occur 10 to 30 feet below the base of the zone. Some 1- to 2-inch-diameter spheroidal and pyritic nodules are aligned along bedding planes in the lower part of the zone.

Exposures of the Tully member are not common. The Bowmanstown exposure and an exposure along the abandoned Lehigh Canal north of North Weissport are the only known complete or nearly complete exposures in the mapped area. Fossiliferous float from the unit is relatively sparse, but usually detectable, except east of the Lehigh River on the north limb of the Lehighton anticline where glacial cover obscures the fossil zone. The float material typically consists of platy pieces of siltstone containing molds of bryozoans and brachiopod valves. The float rock usually has a slight greenish tint on the weathered surfaces.

The fossil zone has no distinct boundaries and is defined by the occurrence of concentrated fossils. The shales comprising the unit are similar to those above and below the member and are typical of the Mahantango Formation of the mapped area. The thickness of the zone is apparently variable. At the Bowmanstown exposure it is 61 feet thick, whereas in poorer exposures elsewhere its thickness may not exceed 20 feet.

Above the top of the Tully member at the Bowmanstown exposure is about 45 feet of shales identical to those of the Mahantango Formation below the fossil zone. Elsewhere, because of lack of exposure, the amount of typical Mahantango rock above the Tully fossil zone is not known, but float material usually suggests the existence of some rock of this type. These rocks grade upward into the materials mapped as Trimmers Rock

Formation; that transition is discussed in the next section. Because of the proximity of the Tully fossil zone to the uppermost rocks of Mahantango lithology and because of the ease of using the Tully float material for mapping purposes as contrasted to the more difficult approach of mapping a gradational boundary, the Tully fossil zone has been used in the mapped area as a mapping boundary for the top of the Mahantango Formation.

### *Microscopic Characteristics*

A total of 127 thin sections from the Mahantango Formation were prepared and examined. The distribution of the thin sections is as follows:

| | |
|---|---|
| Typical shale from various stratigraphic positions | 31 |
| Tully fossil zone | 1 |
| Centerfield fossil zone | 5 |
| Nis Hollow sandstone | 90 |

The various quantitative data cited below are compiled from visual estimates made during examination of the slides.

The typical Mahantango shale is made up of about 81 percent clay, 16 percent microcrystalline silica, 2 percent detrital silt and 1 percent miscellaneous components. The clay is mainly a tight, coherent mass of fine-grained flakes of illite-sericite. These flakes are sometimes randomly oriented and sometimes oriented parallel to bedding, causing "rock extinction" under crossed nicols. The clay composition is listed in Table 7.

Microcrystalline silica occurs as interstitial material and probably accounts for the relative durability of this rock, and is also related to a "graininess" which sometimes imparts a siltstone texture to the shale. Angular quartz grains in the fine- to medium-grained silt size range are scattered randomly throughout and are occasionally concentrated in laminae. Some of the quartz grains are strained. Very fine to medium-grained silt-sized grains of magnetite-ilmenite occur in small quantities in the shale, as do occasional sand-sized muscovite flakes.

Rock in the fossil zones ranges from shale similar to that just described to rock composed entirely of a micritic calcite matrix and sparitic calcite fossil fragments. Most of these calcareous rocks contain some clay, some microcrystalline silica, and some fine-grained silt-sized quartz grains. Small silt-sized grains of pyrite are common, but these make up only a fractional percentage of the calcareous rocks.

The Nis Hollow siltstones consist of quartz silt grains with variable amounts of clay and magnetite-ilmenite. The silt fraction varies from grains touching with a few point contacts and abundant interstitial

## Table 7. *Quantitative X-ray and Chemical Analyses of Selected Mahantango Shale Samples*

A. Quantitative X-ray Analyses (performed by Pennsylvania Geological Survey)

| Sample[1] | Chlorite-Vermiculite | Mica | Kaolinite | Quartz | Feldspar |
|---|---|---|---|---|---|
| 994–2 | 9% | 37% | 15% | 37% | ½% |
| 994–4 | 7 | 32 | 20 | 38 | ½ |
| 994–7 | 5 | 34 | 18 | 41 | ½ |
| 994–9 | 8 | 35 | 14 | 39 | ½ |
| 994–12 | 6 | 38 | 9 | 43 | ½ |
| 195.5.2 | 4 | 33 | 12 | 43 | 1 |
| Average | 7 | 35 | 15 | 41 | ½ |
| Reliability | ±3 | ±6 | ±7–8 | ±4 | ±1 |

B. Chemical Analysis of Sample 195.5.2

| | | | |
|---|---|---|---|
| $SiO_2$ | 61.00% | $Na_2O$ | 0.62% |
| $Al_2O_3$ | 18.15 | $TiO_2$ | .91 |
| $Fe_2O_3$ | 4.08 | LiO.I. | 5.77 |
| FeO | 3.34 | S | .058 |
| CaO | .90 | $CO_2$ | 1.94 |
| MgO | 1.19 | Comb. $H_2O$ | 3.47 |
| $K_2O$ | 4.03 | $H_2O$ @ 120°C | .30 |

[1] Samples 994-2, -4, -7, -9, -12 from exposures along west of U.S. Route 209 immediately north of its junction with Pa. Route 443 in Lehighton. Sample 195.5.2 from O'Neill and others, 1965, p. 109.

material to a solid framework with sutured contacts and almost no interstitial material. The results of a detailed study of the siltstone at Bowmanstown and Lehighton are presented in Table 8. Shales interbedded with the siltstones of Table 8 yielded the following data: at Bowmanstown an average shale contained 62 percent clay and had quartz grains only in the medium- to coarse-grained silt size range; at Lehighton an average shale had 72 percent clay and finer grained silt (16 percent of the shales had fine-grained silt; 50 percent, fine- to medium-grained silt; and 34 percent, medium- to coarse-grained silt).

Strained quartz is the dominant component in these siltstones. A fractional percentage of both plagioclase and alkali feldspar grains occurs in almost every thin section of the siltstones at Bowmanstown, but is almost totally absent in samples from Lehighton. Heavy mineral grains occur occasionally. The magnetite-ilmenite is present as discrete silt-sized grains and as irregularly shaped masses filling interstices. The magnetite-ilmenite is usually partly or almost totally altered to limonite and comprises up to 5 percent of the rock. The quantity of magnetite-ilmenite

Table 8. *Distribution of Siltstone Components in the Nis Hollow Siltstone at Bowmanstown and Lehighton*

| | BOWMANSTOWN | | LEHIGHTON | |
|---|---|---|---|---|
| Grain-size class | % siltstones with mode in grain-size class | % clay per grain-size class | % siltstones with mode in grain-size class | % clay per grain-size class |
| fg-cg silt | 2 | 20 | 10 | 35 |
| fg-mg silt | | | 10 | 30 |
| mg silt | 2 | 40 | | |
| mg-cg silt | 8 | 29 | 40 | 16 |
| cg silt | 68 | 15 | 40 | 8 |
| cg silt to vfg sand | 20 | 8 | | |

decreases as the quantity of clay increases. The clay consists mainly of fine-grained flakes of illite-sericite and occurs as interstitial filling. Muscovite flakes are common.

### *Sedimentology*

The Mahantango Formation includes sediments deposited both from suspension (clays) and currents (silts) in apparently quiet water of unknown depth. The lack of carbonaceous material, typical of the underlying Marcellus Formation, implies increased circulation which allowed oxidation of organic matter. The occasional minute siltstone layers indicate some current activity, but sediment influx to the area was not abundant except during the deposition of the Nis Hollow siltstone. The suggested correlation of the Nis Hollow siltstone with the Montebello sandstone of the Susquehanna River area and the thick development of the Nis Hollow at Bowmanstown probably indicate a temporary increase in sediment influx to the Lehigh River area from a more local source during the same time that abundant sediment influx developed the Montebello to the southwest.

The reoccurring fossiliferous zones indicate periods during which current activity was sufficient to encourage brief development of local biostromes. Light requirements for some of the organisms in these biostromes (e.g., corals) suggest that the water was not too deep, but presence of crinoids indicates a general lack of severe agitation. The layered nature of the fossiliferous zones, the disarticulated crinoid columnals, and the lack of preserved crinoid calices suggest that part or all of these communities were periodically destroyed either by extreme agitation (e.g., storm waves) or as a function of the food chain (i.e., eaten by other organisms). Such destructions were temporary and the communities were quickly reestablished. The complete death of the biostrome at the top of each fossil zone presumably represents a return to completely unfavorable environmental conditions.

The occurrence of more organic rich black shales above the Mahantango southeast of the Lehigh River must represent a return to decreased circulation in the basin.

## UPPER DEVONIAN

In the Lehighton and Palmerton 7½-minute quadrangles, the Upper Devonian includes the Trimmers Rock Formation and the Catskill Formation (Figure 96). The combined thickness of the two formations is 8,914 feet, and they represent the major portion of the entire Devonian System in the mapped area. The bulk of the clastic materials in this system, particularly sandstones and conglomerates, occurs within the Catskill Formation.

The lower part of the Trimmers Rock Formation is lithologically transitional with an underlying shale which occurs above the Tully fossil zone of the Mahantango Formation. The fossils in the Tully are the basis for delineating the biostratigraphic boundary between the Middle and Upper Devonian (Oliver and others, 1969).

The top of the Upper Devonian is, in this report, considered to be transitional with the base of the Mississippian. The Mississippian-Devonian Spechty Kopf Formation lies in this transition zone between the Upper Devonian Catskill Formation and the Mississippian Pocono Formation. For a further discussion of this boundary, see the section on the Spechty Kopf Formation.

### Trimmers Rock Formation

The Trimmers Rock Formation, 1,056 feet thick, is fully exposed in the south limb of the Weir Mountain syncline in an extensive roadcut on Pa. Route 248 along the east bank of the Lehigh River between Bowmanstown and Parryville. The exposure in this roadcut is the reference section of this report (Figure 93; measured section 8). Extensive, though not complete, exposures also occur downslope from Pa. Route 248 along the railroad cut on the east bank of the Lehigh River; on the west bank of the river just south of Pa. Route 443; on the Northeast Extension of the Pennsylvania Turnpike just south of Walcksville; and on the Northeast Extension of the Pennsylvania Turnpike just north of West Bowmans which Willard (1957) described. In addition, major outcrops of the Trimmers Rock occur just south of, and on the access ramps of, the Mahoning Valley exit of the Northeast Extension of the Pennsylvania Turnpike (Plate 1). Other good exposures of Trimmers Rock can

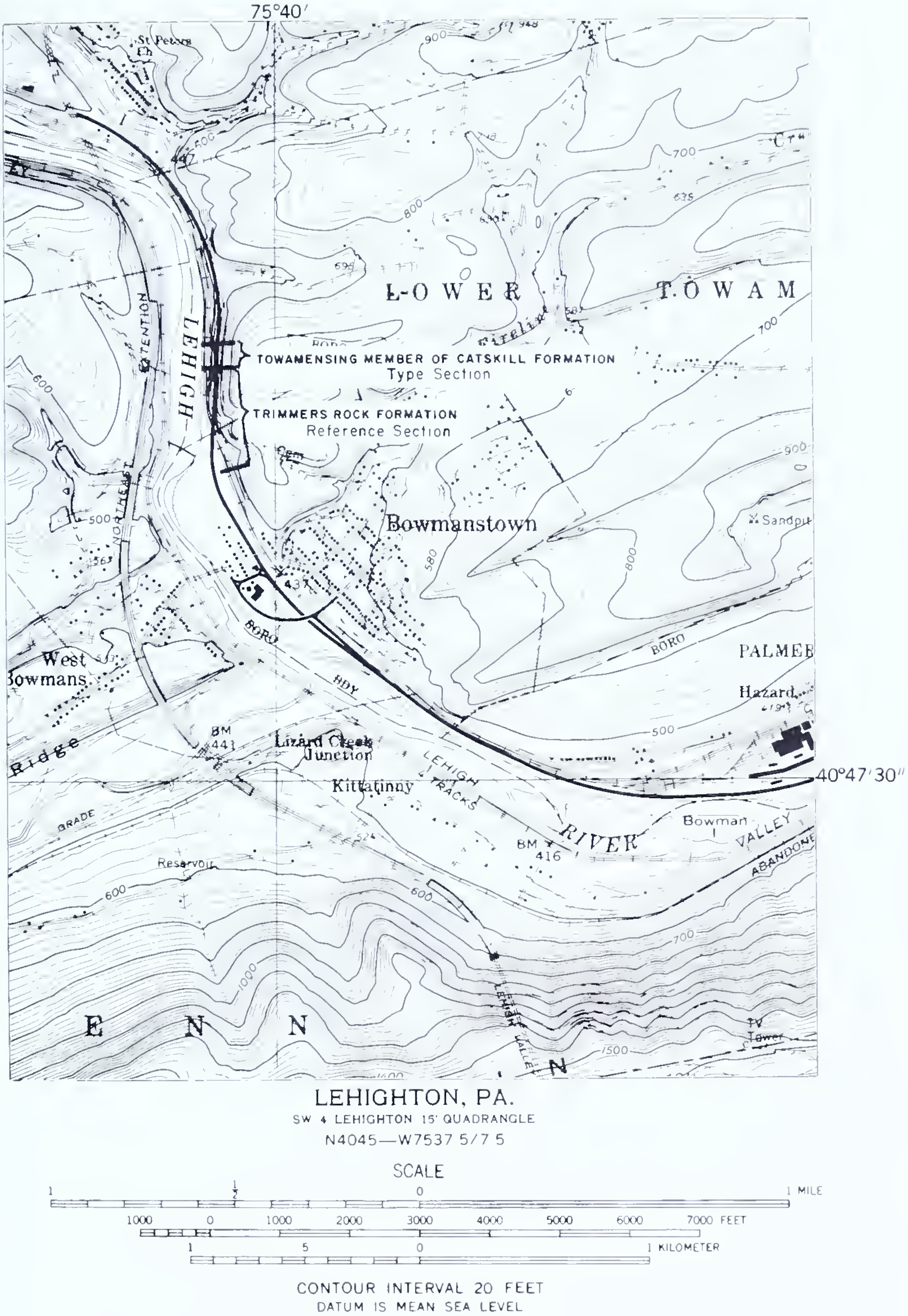


Figure 93. Location map of Trimmers Rock Formation reference section and Towamensing Member type section.

be observed at Harrity on U.S. Route 209 east of the Mahoning Valley exit; at the north edge of Jamestown along the west side of U.S. Route 209; and along the railroad cut on the east bank of the Lehigh River north of Weissport and eastward along strike from the exposures at Jamestown.

The Trimmers Rock was given formation status by Hoskins (1963, p. 203) in central Pennsylvania. Klemic and others (1963) reported a thickness of 1,300 feet for the Trimmers Rock in the Lehighton 15-minute quadrangle. They placed the bottom of the Trimmers Rock Formation directly upon the top of the Mahantango Formation, but included the Tully fossil horizon in the basal portion of the Trimmers Rock rather than in the upper part of the Mahantango.

Plate 3 shows the boundaries of the Trimmers Rock Formation used by previous authors in comparison to the boundaries used in this report. Willard and others (1939), Cooper and others (1942), and Dyson (1967) placed the top of the Trimmers Rock at the highest occurrence of marine fauna. In the present report, the formation is considered a lithologically distinctive mappable unit whose boundaries are not based on fossil content.

The siltstones and shales of the Trimmers Rock Formation underlie hills which stand out topographically from the valleys formed by the shales in the upper part of the Mahantango Formation (Plate 1). The relief of hills underlain by the Trimmers Rock Formation increases toward the top of the formation. The upward increase in relief is related both to a general increase in grain size and to an increase in the number, frequency, and thickness of massive, coarse siltstone beds and a concomitant decrease in fissile fine-grained siltstones and shales. The 95 units shown in measured section 8 are not single sedimentation units but rather are larger assemblages of beds of similar aspect, that is, beds having similar parting properties and parting thicknesses, color, lithology, and primary sedimentary structures.

The Trimmers Rock Formation is made up almost entirely of siltstone with minor amounts of shale. The siltstones comprising the bulk of the formation are gray (N2 to N5). The grain sizes of the siltstones were classified in the field according to megascopically defined categories of fine, medium, and coarse grained. In coarse-grained siltstones, the individual quartz and mica fragments can be seen without a hand lens on a fresh surface normal to bedding. These visible grains do not attain the size of very fine grained sandstone on a sand gage. The term fine-grained siltstone is applied to units which on a fresh surface have the appearance of a very compact shale, but which have a gritty texture when bitten. Bed parting properties are not considered in this definition of fine-grained siltstone. Medium-grained siltstone includes rocks with grain sizes ranging between the grain sizes established for coarse- and fine-grained siltstone.

The Trimmers Rock Formation has abundant primary sedimentary structures which give insight to the sedimentary origin of the formation. The most obvious and common primary sedimentary structures are massive graded siltstone beds alternating with fissile parallel-laminated siltstone beds. Graded siltstone beds occur in almost half of the 95 units measured; parallel-laminated coarse- and fine-grained siltstones make up approximately 57 percent of the units. Cross-laminated units are relatively rare. Fine-grained siltstone beds, particularly those occurring at the tops of graded beds, commonly have burrows filled with coarse-grained siltstone.

Graded units in the Trimmers Rock do not contain the complete sequence of primary structures in Bouma's (1962) idealized sequence (a-e). Three of the five components of Bouma frequently occur—massive siltstone at the base (a), grading upward into parallel-laminated coarse- and fine-grained siltstones (b and/or d), followed in turn by a fine-grained siltstone layer (Bouma's pelitic layer, e).

Ripple laminations (c) are not present in the reference section. Cross laminations, though not common in the reference section, do occur, and consist of two superposed parallel-laminated zones, the upper zone dipping slightly more steeply and abutting the lower. The two zones are separated by an apparent erosion surface. The tops of the laminations in the upper zone are tangential with, and merge into, the overlying parallel-laminated beds. These planar cross laminations are considered part of Bouma's b and d units; however, because current-ripple laminations (Bouma interval c) are lacking, the distinction between Bouma's intervals b and d cannot be made.

Ball-and-pillow structures (Potter and Pettijohn, 1965) are common in the Trimmers Rock Formation, particularly in the upper portions where massive coarse siltstone beds have thicknesses of more than ten feet. Ball-and-pillow structures at the base of massive unit 75 (measured section 8) are shown in Figure 94. These load-cast structures reach eight feet in length and two feet in thickness in the observable dimensions normal to bedding. Frakes (1963) described these structures in the Trimmers Rock in detail. Sole markings at the bottoms of these massive beds are not common in the Trimmers Rock in the Lehigh River area, but McIver (1961) has shown that a variety of sole markings frequently occur in this formation in other locales.

There are many other primary sedimentary structures in the Trimmers Rock Formation at its reference section (measured section 8). In addition to the graded and parallel-laminated beds, some units have discontinuous or wavy laminations. There are different types of contacts between sedi-

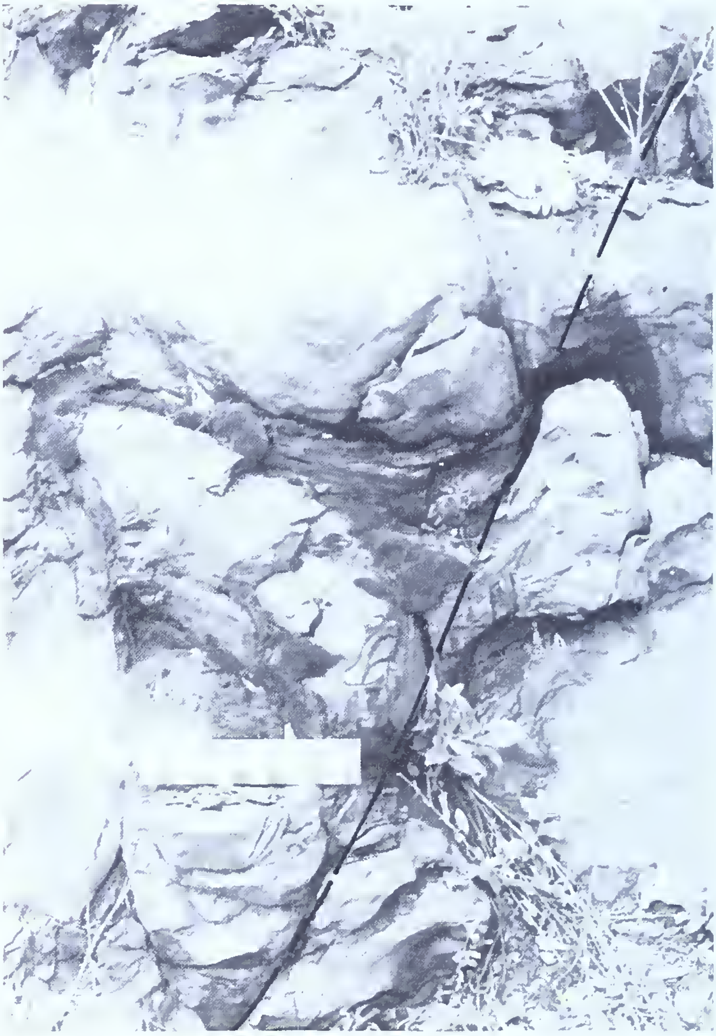


Figure 94. Ball-and-pillow structure in the Trimmers Rock Formation, unit 75, measured section 8. Dashed line shows base of bed.

mentation units, including sharp, planar contacts, rippled or undulatory contacts, and erosional contacts having evidence of a scour origin. Scour-and-fill structures are present, and numerous shale chips occur at or near the base of siltstone beds resting upon fissile shale. Burrows, tracks, and trails, and traces of carbonaceous material having the appearance of fine blades of grass have been observed on the upper surfaces of the pelitic interval in graded sequences.

There are two types of shelly fossil occurrences in the Trimmers Rock: (1) the common occurrence of scattered individual shell fauna, generally brachiopods, on bedding planes; and (2) the less frequent, but more noticeable, occurrence of lenticular masses of calcareous shell fragments.

These lenticular masses are as much as 2 feet thick and occupy what appear to be channels which have scoured the underlying bed. Figure 95 shows one of these lenticular zones made up entirely of shell fragments at the base of unit 72 in the reference section (measured section 8).

The top of the Trimmers Rock Formation at the reference section is placed beneath the first occurrence of a tough, massive, fine- to very fine grained, medium-gray sandstone which is the base of the overlying Catskill Formation. This boundary is readily mappable in the Lehighton quadrangle and in contiguous areas. The uppermost units of the Trimmers Rock Formation show abundant evidence of bioturbation, wavy bedding and wavy laminations, and contain the only occurrence of flaser

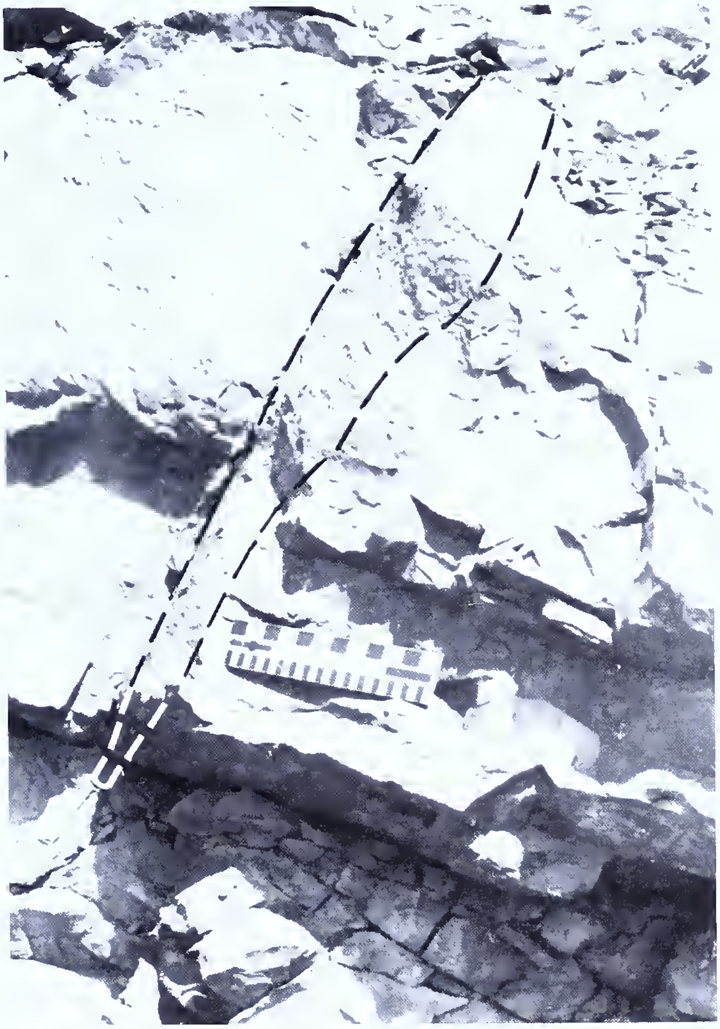


Figure 95. Lenticular fossil zone, Trimmers Rock Formation, unit 72, measured section 8. Dashed line outlines zone.

structures in the formation. The flaser structures are similar to those described by Reineck (1967).

### *Sedimentologic Origin of the Trimmers Rock Formation*

The primary structures in the Trimmers Rock Formation are associated with turbidite deposits. Bed thickness increases upward, suggesting the development of a more intense energy regime and an increased sediment supply, apparently resulting from a gradual shift from offshore to nearer shore conditions in the area of the Trimmers Rock reference section. The burrow mottling, flaser structures, and wavy bedding in the upper part of the formation also suggest a shallower water or a nearer shore environment than do the turbidites which form the bulk of the formation.

The lithology and primary structures indicate that these deposits accumulated ahead of an outbuilding coastal margin in the area between debouching river systems and the shelf environment. This area of deposition is here considered to be analogous to the prodelta area of Fisk and others (1954). The prodelta is defined as the subaqueous portion of the delta platform where fine detritus accumulates ahead of the actively building distributary mouth bars forming on the delta front. Coleman and Gagliano (1965) listed many criteria for defining prodelta deposits; these include the regular repetition of sedimentary structures, lenticular laminations, remains of scattered shells and plants, and small burrows restricted to definite zones. All are characteristic of the Trimmers Rock Formation at the Lehigh River.

## Catskill Formation

The most complete and continuous exposure of the Catskill Formation in the Lehighton 7½-minute quadrangle occurs along the Lehigh River. The lower portion of the Catskill Formation is exposed in the Weir Mountain syncline in the roadcuts along the east bank of the Lehigh River on Pa. Route 248 (Plate 1). The major portion of the Catskill is exposed on the west bank of the Lehigh River on U.S. Route 209 between Lehighton and Jim Thorpe in the north limb of the Lehighton anticline. Both the transition at the base of the Catskill to the underlying Trimmers Rock Formation and the transition at the top of the Catskill to the overlying Pocono Formation are fully exposed. The Catskill Formation is 7,858 feet thick in the Lehighton quadrangle.

One purpose of initiating detailed mapping in the Lehighton and Palmerton quadrangles was to establish mappable rock units within the thick and apparently complex Catskill Formation. The two quadrangles were selected as a starting point for mapping because the most complete exposure of the Catskill in northeastern Pennsylvania occurs within their boundaries. The exposures along the railroad cuts in the Lehigh River valley are not new; the region has been observed and described by other workers in the past. Inevitably, the problems of nomenclature, criteria for defining formation and member boundaries, and relations of stratigraphic subdivisions to type locations elsewhere were in need of resolution. A summary of these problems is given below, followed by a discussion of the proposed solutions.

### *Previous Work*

The first attempt to subdivide the Upper Devonian Vergent series (Portage and Chemung) and the Ponent series (Catskill) of Rogers (1858) was made by I.C. White (1881). Later, White (1882) distinguished two "series" within the Upper Devonian in northeastern Pennsylvania: the Chemung series (approximately equivalent to the Trimmers Rock Formation of this report), which lay above the Middle Devonian Hamilton, and the Catskill series, which lay above the Chemung and below the base of the Pocono Formation. White relied primarily upon lithologic characteristics and vertical succession in making his distinctions between Chemung and Catskill rocks and between the members he defined as comprising the Catskill "series." He (White, 1882, p. 104) saw no lithologic or faunal evidence of the Portage series in northeastern Pennsylvania.

White (1882) subdivided the Catskill into several members along the Lehigh River between Lehighton and Mauch Chunk (now Jim Thorpe). He had defined these members earlier in Wayne and Susquehanna Counties (White, 1881). Emphasis upon lithologic properties and their vertical succession underlies his interpretations of the stratigraphic relationships between the two regions.

Lesley (1892, p. 1434-1455; 1545-1599) modified White's Catskill-Chemung boundary so that it coincided with the uppermost occurrence of Chemung fauna. The new boundary was a separation of what were thought to be marine (Chemung) and nonmarine (Catskill) conditions; the presence of shelly fauna constituted marine rocks whereas the absence of shells and the presence of red beds constituted nonmarine rocks. Although Lesley was aware that lithologic members defined by White crossed this faunal boundary, he and later workers ignored the discrepancies between the lithostratigraphic and biostratigraphic boundaries. Instead, emphasis was placed upon delineation of the boundary between the marine and nonmarine rocks, to such a degree that little effort was made to trace out rock units. An involved nomenclature problem developed, because the base of the Catskill became equated with the marine-nonmarine boundary despite the continued use of the lithologically defined Catskill member names of White (1881).

Willard (1936b) and Willard and others (1939) also used the lithostratigraphic units in a biostratigraphic framework in an attempt to map White's Catskill members (with some modifications) on a 15-minute scale over much of northeastern Pennsylvania (maps on file, Pennsylvania Geological Survey). Willard's member boundaries bear little relationship to lithologically and topographically expressed rock units in the region. Willard's Catskill members were not based on criteria now used in defining a member or formation (American Commission on Stratigraphic Nomenclature, 1970) and could not be successfully applied in the present mapping program because: (1) his members encompassed widely different rock sequences which can be readily separated in measured sections, traced on aerial photographs, and mapped; (2) areally, his Catskill-Chemung boundary crossed mappable rock units; (3) his members at the Lehigh River, which retained some of the names originally used by White, were not the same units to which White (1882) originally applied these names at the Lehigh River.

Klemic and others (1963) partially resolved the problem of Catskill nomenclature in the northern half of the Lehighton 15-minute quadrangle by the introduction of two locally named, lithologically defined members—the Walcksville and Beaverdam Run Members. They considered the Walcksville Member, the first red beds above the Trimmers Rock Formation, to be the basal unit of the Catskill Formation. White (1882) had called these red beds the Montrose Member along the Lehigh River. Willard (1957) did not include them in the Catskill Formation because the overlying member (Beaverdam Run of Klemic and others, 1963; Delaware River Flags of White, 1882) contained crinoid columnals and other evidence of marine conditions. Willard (1957) placed the Catskill boundary above the marine rocks called Beaverdam Run by Klemic and others (1963).

In addition to naming the Walcksville and Beaverdam Run Members, Klemic and others (1963) retained the use of the three members (Damascus, Honesdale, and Cherry Ridge) used by Willard and others (1939) and Willard (1957) at the Lehigh River section. They did not correlate these units to the type locations of White (1881), a necessary operation in view of the absence of previous mapping by White (1882) or by Willard and others (1939) from the type locations to the Lehigh River.

Glaeser (in Frakes and others, 1963) placed the Catskill boundary at the same horizon as did Willard (1957) and was not cognizant of the two underlying Catskill members, the Beaverdam Run and Walcksville, of Klemic and others (1963). Glaeser (1963) subdivided what he, at that time, considered to be the Catskill Formation into a number of informally defined members ("A" through "O"), based on lithologic criteria.

Several of these informal members have since been combined into formal members (Figure 96), and the base of the Catskill has been altered to include rocks that were previously considered by Glaeser (1963) to be the upper part of the Trimmers Rock Formation.

### *Solution to the Nomenclature Problem of the Catskill Formation*

Mapping by the authors in the Lehighton and Palmerton quadrangles was preceded by an examination of the original type Catskill member locations of White (1881) to determine whether White's lithostratigraphic framework was valid. Because White (1882) first applied member names to the section at the Lehigh River, these names had precedence. The precedence seemed appropriate when the writer (Glaeser), in examining the remeasured Upper Devonian section at the Lehigh River (Glaeser, 1963; Frakes and others, 1963), observed that lithologically distinctive parts of the nearly 8,000 foot section matched White's subdivisions of the same section very closely. Direct comparison of the remeasured section with White's was made possible by recognizing that part of the rocks which Glaeser (1963) had included in the Trimmers Rock Formation were more allied to the overlying Catskill rocks than to the underlying lithologies of the Trimmers Rock. Not only were the rocks assigned to the Beaverdam Run and Walcksville (Klemic and others, 1963) logically a part of the Catskill, but a sandstone unit, nearly 200 feet thick, beneath the lowest red units of the Walcksville contained lithologies and primary sedimentary structures common to Catskill and not Trimmers Rock lithologies. Joseph F. Wietrzychowski, a co-worker at the Pennsylvania Geological Survey in the mapping program (1963-64), first recognized this sandstone as a mappable unit separating the gray siltstones of the Trimmers Rock Formation from the lowest red-bed member of the Catskill Formation, the Walcksville Member.

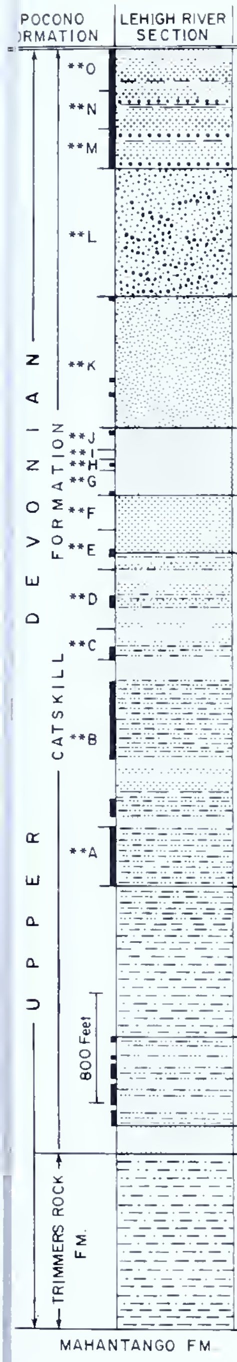
Having compared White's (1882) unit descriptions of the Lehigh River section with Glaeser's (1963) description, and having adjusted the base of the Catskill to include the 200-foot sandstone unit previously assigned to the Trimmers Rock Formation, an attempt was made to compare White's unit delineations at the Lehigh River section with the units at his type locations in Susquehanna and Wayne Counties. Neither White nor later workers had mapped the units from the type localities to the Lehigh River outcrops.

In order to determine whether a correlation could be made between the members at White's (1881) type locations and his members at the Lehigh River, all outcrops around the type locations were remeasured and described in detail. Appendix 1 contains these measured sections and a summary description of the sections. The remeasured type sections were then compared to determine whether they contained readily discriminable rock units which could be identified beyond the areas of their original definition. In addition, the physical properties of the rocks at each type location were compared to the physical properties of the rocks of White's (1882) subdivisions at the Lehigh River.

Study of all accessible outcrops at each of White's (1881) type locations (Appendix 1) led to the following conclusions:

1. The type locations occur at widely separated sites on both flanks of the Lackawanna syncline (Figure 174 in Appendix 1) with no continuous exposures or topographic expression of units between any two type localities; thus structural and stratigraphic continuity among White's (1881) type sections could not be established.
2. Lithologic comparison among the type sections indicates that White (1881) did not establish a simple rock-stratigraphic sequence. The similarities in lithologies and primary sedimentary structures in rocks at Montrose, New Milford, and Mount Pleasant, and in rocks at Honesdale, Cherry Ridge, and Elk Mountain (Figure 175, Appendix 1) preclude mapping these type members as separate rock units even within the counties in which they were defined. White (1881, p. 40 and 1882, p. 97) assumed that, in moving geographically from his lowest type location (Starrucca) to his uppermost type location (Mount Pleasant), the projection of dips and increasing elevations resulted in an ascending stratigraphic succession.
3. Comparison of lithologies and primary structures observed at each type section with lithologies and primary structures at the Lehigh River section indicates that, because of similarities among White's type members, all of them can be related to one limited portion of the Catskill section at the Lehigh River. In addition, three lithologically distinctive units mapped in this study—the Beaverdam Run, Clark's Ferry, and Duncannon Members—have no lithologic counterparts at any of White's (1881) type locations.
4. Despite the fact that White (1882) applied names to presently recognized rock units in the Lehigh River section, the derivation of these names from type locations whose rock units, taken together, do not constitute a recognizable stratigraphic succession precludes their use in the present study.

The accessibility, completeness, and vertical stratigraphic continuity of the Catskill Formation at the Lehigh River section warrants its continuation as the Catskill reference section for northeastern Pennsylvania (Glaeser, 1963) and justifies the designation of type member names there. The formation is divided into nine members, of which four have already been named. Figure 96 lists the formal subdivisions of the Catskill Formation at the Lehigh River reference section and gives a summary of salient characteristics of each member.



| FORMATION OR MEMBER | THICK-NESS | DESCRIPTION | ORIGIN |
|---|---|---|---|
| DUNCANNON MEMBER | 968′ | Red conglomerates, sandstones and siltstones arranged in fining-upward cycles. Crossbeds common. Siltstones and shales, often rippled and mud-cracked, are fissile. Scour and intertongued beds common in lower third; above, fining-upward sequences lack conglomerates and dominance of red color. | Meandering rivers |
| CLARK'S FERRY MEMBER | 904′ | Nonred, medium- to coarse-grained sandstones and conglomerates. Massive, planar crossbeds. Bimodal-bipolar vectors. Bed tops often strewn with fine-grained rock fragments. Giant ripples and parting lineations common. | Braided rivers |
| BERRY RUN MEMBER | 985′ | Nonred, medium- to fine-grained sandstones dominate. Few red siltstones up to 40 feet thick in upper part. Minor conglomerates. Crossbeds common. Leached limonite-rich zones with shale and round carbonate fragments. | Braided rivers |
| SAWMILL RUN MEMBER | 424′ | Nonred, dominantly fine- and very fine grained sandstones, commonly crossbedded. Some sandstones calcareous. Basal, middle and upper red siltstones. Minor shale. Leached limonite-rich zones with shale and round carbonate fragments. | Braided rivers |
| PACKERTON MEMBER | 416′ | Dominantly medium- to fine-grained, well-sorted sandstones; commonly crossbedded. Minor fine conglomerates, siltstones and shales. Some calcareous sandstones. Leached limonite-rich zones with shale and round carbonate fragments. | Braided rivers |
| LONG RUN MEMBER | 2363′ | Predominantly red, parallel-sided beds of massive, fine- to very fine grained sandstones and red siltstones and fissile shales. Sandstones more prominent upward. Several upward-fining successions in upper part. | Delta plain |
| BEAVERDAM RUN MEMBER | 963′ | Nonred. Principally siltstone with some very fine grained sandstones. Parallel-sided, massive and fissile beds alternate. Ball-and-pillow structures prominent; some slumped. Tentaculites and crinoid columnals at bases of many massive beds. | Prodelta |
| WALCKSVILLE MEMBER | 645′ | First red-bed sequence above Catskill base. Parallel-sided, massive and fissile, nonred and red siltstones and sandstones. Abrupt lateral color and grain-size changes common. Some upward-fining successions. | Delta plain |
| TOWAMENSING MEMBER | 190′ | Gray, fine- to very fine grained sandstones and coarse siltstones. Many undulatory and scoured surfaces. Shale-clast conglomerates. Poorly sorted sandstones contain carbonaceous debris. Churned and burrow-mottled siltstones. Some burrowed zones graded, shale-capped, and rippled or mud-cracked with infilling of overlying sediment. Near middle, some graded beds. | Delta front |
| TRIMMERS ROCK FORMATION | 1056′ | Gray siltstones. Alternating massive graded (coarse- to fine-grained siltstone) and parallel-laminated beds. Cross-laminations minor. Fine siltstones at tops of graded beds commonly burrow mottled. Upward bed thickness increases and ball-and-pillow structures (2′ x 8′) occur: Brachiopods associated with shale chips at base of some graded beds and in lenticular zones "scouring" underlying bed. Carbonaceous material often in fine siltstone at top of graded beds. | Prodelta |

Figure 96. Formal subdivisions of the Catskill Formation at the Lehigh River section with summary of salient characteristics of each member. Black bars to left of patterns denote red beds. Asterisks indicate informal members of Glaeser (1963).

## Towamensing Member

The Towamensing Member is the basal member of the Catskill Formation and consists predominantly of sandstones. The Towamensing is the first sandstone sequence above the Middle Devonian Palmerton Formation (Plate 3). The member is mappable throughout the Lehighton quadrangle, but it has not heretofore been treated as a separate, mappable entity.

The name Towamensing (pronounced Ta-men'sing) is derived from Towamensing and Lower Towamensing Townships in Carbon County east of the Lehigh River. The section occurs in the steep south limb of the Weir Mountain syncline. The basal unit is a 4-foot-thick, very fine grained, massive, medium-dark-gray (N4) sandstone (measured section 9). The basal contact with the underlying carbonaceous, fissile, fine siltstone of the Trimmers Rock Formation is sharp, and load casts of sandstone extend into the upper surface of the siltstone. There is six inches of relief on this surface. The topmost unit of the Towamensing Member is seven feet thick and has fine- to medium-grained sandstone in its lower four feet, grading upward into fine-grained sandstone. The color of this uppermost unit ranges between medium-bluish gray (5B5/1) and medium-greenish gray (5G5/1). The top 16 inches is transitional into the overlying Walcksville Member and is marked by a color change to red with a "zebra-striped" color lamination of red and bluish to greenish gray in the interval of change. This transition zone is somewhat mottled and fresh surfaces are highly light reflective, apparently because of silica cement.

Based on megascopic field description, the Towamensing Member is predominantly a well-indurated fine- to very fine grained sandstone; some units are medium grained. Certain layers, when observed on a fresh surface, are dotted with pinhead-sized rust-colored hematite. The Towamensing Member also contains siltstones, the bulk of which are coarse grained and medium gray (N5), but some of which are medium-dark gray (N4) and medium grained. Some of the medium-dark-gray medium-grained siltstones are micaceous. The siltstones are frequently graded, and some are interlaminated or interbedded with sandstones. Also, there are minor amounts of dark-gray (N3) to medium-dark-gray (N4) shales. Measured section 9 gives a bed-by-bed description of the type section of the Towamensing Member.

Many sandstone units in the Towamensing type section contain abundant plant material or carbonaceous debris. The carbonaceous sandstones are matrix rich and poorly sorted, commonly have erosional bases, and contain shale chips. Thin, discontinuous coaly lenses occur in units 79, 69B, 68-66, 55-53, 52, 49 and 48 (measured section 9).

Erosional and/or undulatory surfaces occur at the base of many Towamensing sandstone beds where the beds rest upon siltstone units. In some of the more massive sandstone beds, the undulatory base has up to six inches of relief because erosion has cut out parts of the underlying unit. Occasionally, shale clasts and pieces of the underlying bed occur immediately above the scoured surfaces. Micro-scour-and-fill structures were observed in units 75 and 55-53. Unit 2, just above the basal contact of the Towamensing Member, is slumped, having large angular disordered blocks of sandstone in a mixed lithologic assemblage of shale, siltstone, and sandstone which lacks planar bedding. Figure 97 illustrates this zone of slumping.

Burrow-mottled siltstones occur in units 81, 59, 38, and 21 (measured section 9) of the Towamensing type section. Some graded beds have also been observed; fine-grained sandstone at the base grades upward in a few inches to medium-grained siltstone which is, in a few places, capped by a ripple-marked shale layer. Some of these capping shale layers contain traces of plant fragments; others have sand-filled burrows. Commonly, the graded units have an undulatory contact with the underlying unit. Erosion has removed the uppermost fine detritus from the tops of some of the graded units.

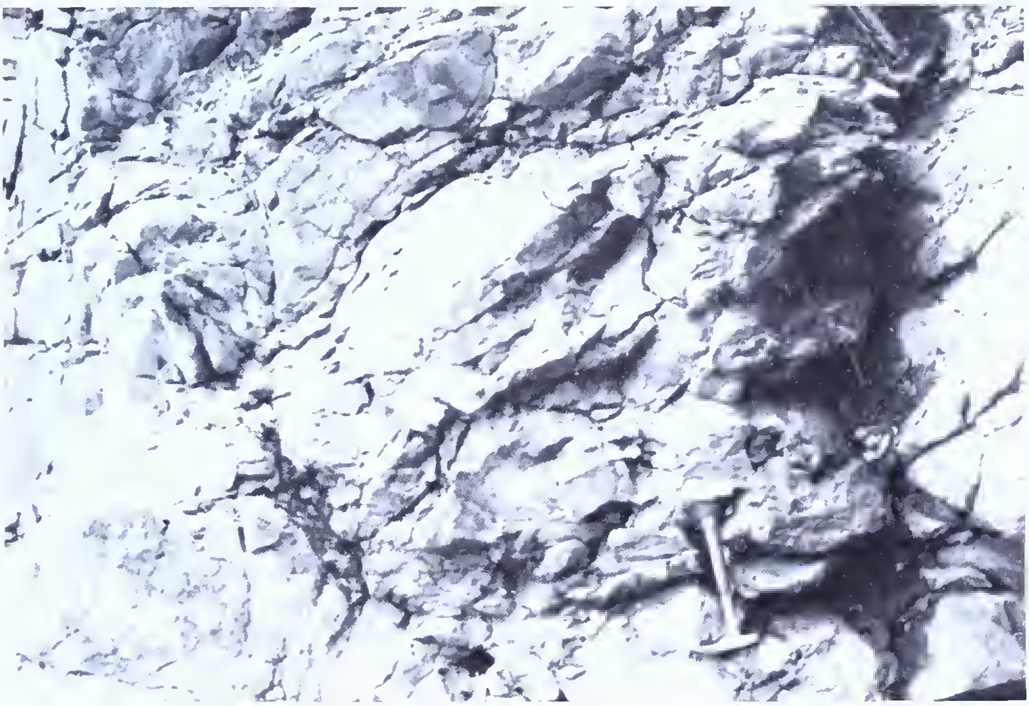


Figure 97. Slumped and chaotic bedding, Towamensing Member of Catskill Formation, unit 2, measured section 9.

Other types of primary sedimentary structures, such as ripple bedding or large-scale crossbedding, were not observed at the type section, possibly because the roadcut in which the section occurs was recently excavated (1963). In other good exposures in the Lehighton and Palmerton quadrangles, the effects of many years of weathering have accentuated primary sedimentary structures not seen at the type section. Just west and downslope of the type section along the railroad cut on the east bank of the Lehigh River, the bedding is very massive, but weathering has revealed traces of parallel laminations within the thick beds.

North of the type section at Harrity (Plate 1), just east of the Pennsylvania Turnpike exit at U.S. Route 209, exposures in the north side of the first sharp bend in the road show massive, parallel-laminated sandstones of the Towamensing Member. The lower portion of the section consists of several feet of interbedded sandstone typical of the Towamensing and gray siltstone of the upper part of the Trimmers Rock Formation. Within this zone of interbedding, one siltstone unit is maroon. Above, in the main portion of the Towamensing exposed at this outcrop, bedding is flaggy (1-3 inches thick) and parallel laminated. Near the uppermost units at the bend, steep planar foreset sandstone beds dipping southeastward are the only crossbeds observed in the Towamensing. This zone of crossbedding overlies a thick, planar sandstone bed, the surface of which has well-preserved pelecypod molds (Figure 98). Exposure of this unit along joint planes reveals that these "clams" burrowed 6 to 12 inches vertically downward into the sandstone bed (Figure 99). Berg (1973) has given a summary of the important features and paleontologic significance of these burrows. Above this burrowed bed are cuspate-form beds strewn with quartz pebbles. These cuspate beds spread outward toward the northwest and the abrupt ridge between them becomes less pronounced in that direction.

### *Sedimentologic Origin of the Towamensing Member*

The dominance of sandstone, the shallow-water character of the primary sedimentary structures, and the presence of plant fossils suggest that the Towamensing formed in the distributary-mouth zone, and was, therefore, deposited in an area that was nearer to the shore than the area of deposition of the underlying Trimmers Rock Formation. The Towamensing Member thus represents the onset of deposition of delta-front sandstones after cessation in the development of an offshore delta platform (the Trimmers Rock prodelta deposits). The deposition of the Towamensing Member in a nearshore area is also suggested by the presence of interbedded siltstones, some of which are graded and indistinguishable from beds in the Trimmers Rock Formation. Erosional and

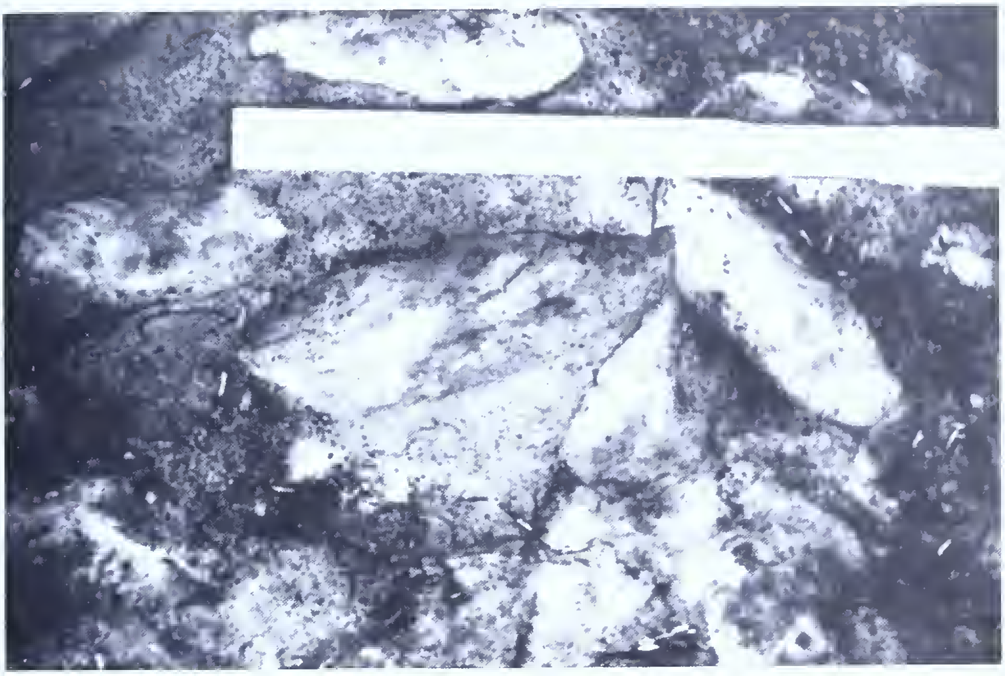


Figure 98. External molds of pelecypod shells along bedding plane, Towamensing Member of Catskill Formation at Harrity, U.S. Route 209, just east of Turnpike exit.

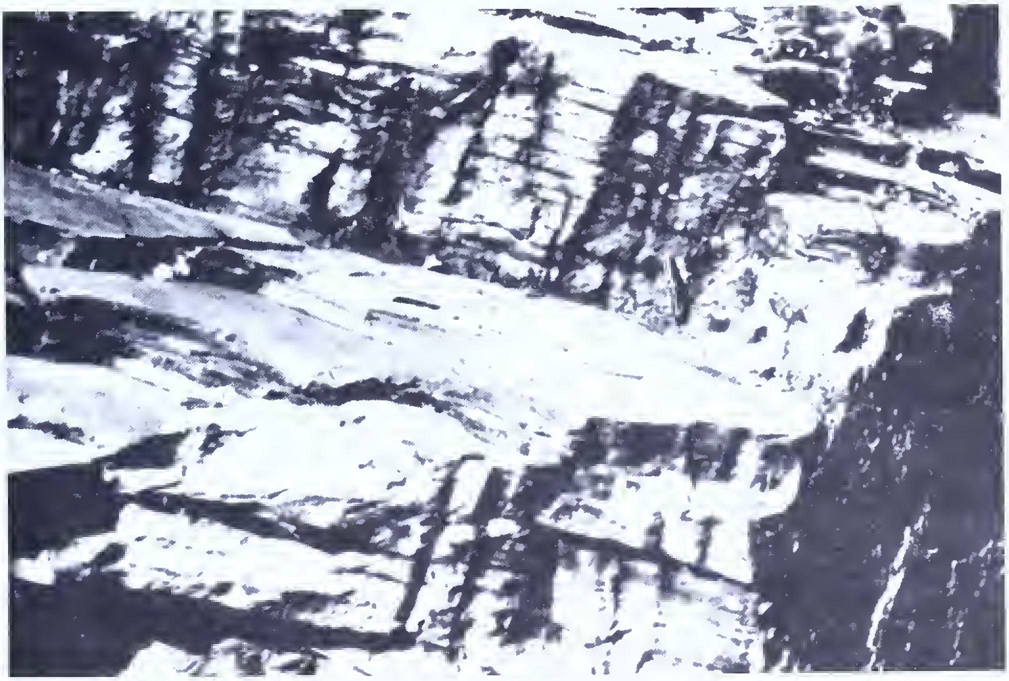


Figure 99. Columnar burrows in Towamensing Member of Catskill Formation at Harrity, U.S. Route 209, just east of Turnpike exit.

undulatory contacts between beds and scour-and-fill structures indicate deposition, at least at times, above the depth of wave base.

Allen (1965c) described features similar to those observed in the Towamensing Member in delta-front deposits of the Niger delta. Delta-front deposits of the Mississippi River delta have been described by Fisk (1961) and by Coleman and Gagliano (1965).

Delta-front deposits are aprons of river-transported clastics which develop as distributary-mouth bars and often are redistributed by longshore currents along the coastline. Offshore and stratigraphically downward, delta-front sandstones pass directly into siltstones and shales of the prodelta deposits (Trimmers Rock). The rather striking uniformity in thickness, texture, and grain size of the Towamensing within the Lehighton quadrangle implies that this region at the time of accumulation was peripheral to, rather than at the immediate site of, active building of river-mouth bars. More lenticularity in the unit and variable textures might be expected within the immediate area of active bar development. Probably the Towamensing in the Lehighton quadrangle area is largely a product of lateral shifting of river-mouth detritus by longshore currents. The pelecypod burrows, southeastward-dipping crossbeds, and cuspate-bedding structures at the Harrity section suggest that a beach or an emergent offshore bar developed and is preserved at that locality.

## Walcksville Member

The Walcksville Member of the Catskill Formation was defined by Klemic and others (1963, p. 26). The type section was measured and described by them (p. 24-25) at a nearly complete exposure along the east side of the Northeast Extension of the Pennsylvania Turnpike (Figure 100) where the Turnpike cuts through the Indian Hills near Walcksville (Plate 1). The type section is 710 feet thick. The Walcksville Member is mappable because about half of its units, especially the siltstones, are red and thus contrast both in float and outcrop with the underlying Towamensing Member and the overlying Beaverdam Run Member, both of which are nonred. Klemic and others (1963) called the Walcksville the first nonmarine member of the Catskill Formation because of the absence of marine fossils at the type section. The lowest unit in the type section of Klemic and others is included in the underlying Towamensing Member in the present study.

The red color in the Walcksville at its type section is confined almost entirely to siltstone and shale intervals. Sandstones are most commonly gray and gray green and are all fine and very fine grained. They are generally massive with parallel laminations; none are crossbedded. Some of the sandstones are "dirty," and weather more readily than the other

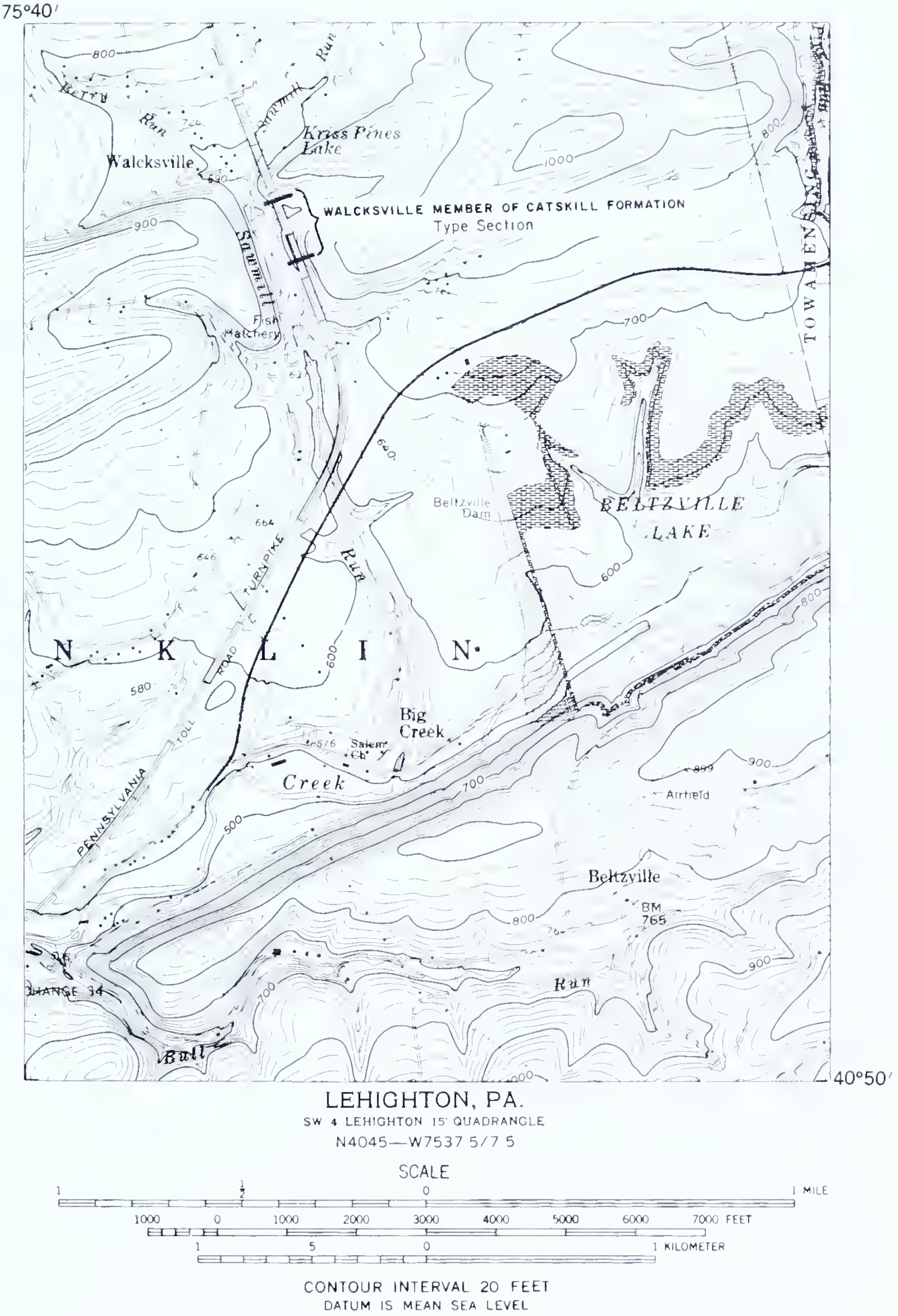


Figure 100. Location map of Walcksville type section.

sandstones in the type section; these sandstones are highly micaceous and typically gray. Plant fragments or impressions are rarely preserved in these sandstones.

In several units of the type section, grain size fines upward. Absence of crossbeds and a distinctive scoured basal contact suggests these fining-upward units are not the same as the fluvial cyclothems of Allen (1964).

Several color gradations occur, usually from red upward into gray or gray green. At the zone of color change there are concentrations of nodules, commonly calcareous, which have weathered rusty orange. There are six occurrences of these nodules in the Walcksville type section, and in every case they are in siltstone. None is associated with upward fining of grain size and none occurs in sandstone. Because these calcareous nodules are consistently found in the zone between red siltstones (below) and green siltstones (above), they apparently are a primary feature of the sediment and probably represent, as does the sediment color, the boundary between oxidation (below) and reduction (above) of the iron oxides in the deposit. Such change in oxidation potential affects both iron and carbonate and apparently is the controlling factor in carbonate precipitation.

No complete exposure of the Walcksville occurs in the Lehighton quadrangle. A reference section was measured for the present report along the road north of Weissport east of the Lehigh River in exposures cut through the Indian Hills just south of Long Run (Figure 100). Measured section 10 contains the detailed description of this section and the section is generally described below. Other good exposures of the Walcksville occur in the cuts along Pa. Route 248 between Parryville and Bowmanstown in the Weir Mountain syncline, where the contact with the underlying Towamensing Member is exposed. However, the middle parts of the Walcksville are complexly involved in tight folding and bedding-plane thrusting in the trough and flanks of the Weir Mountain syncline (Glaeser, 1967). The uppermost beds of the Walcksville Member do not occur in this portion of the syncline, although eastward, up the plunge of this fold, the youngest Walcksville rocks are preserved beneath the overlying Beaverdam Run and Long Run Members (Plate 1). Another less complete exposure of the Walcksville occurs along the railroad just north of Jamestown, along the west bank of the Lehigh River. The uppermost beds of the Walcksville are exposed along U.S. Route 209 just south of the reference section of the Beaverdam Run Member; the contact with the overlying Beaverdam Run Member is visible at this exposure. There is also a partial exposure of the Walcksville on the Pennsylvania Turnpike where it cuts through the south limb and trough of the Weir Mountain syncline just south of the Turnpike bridge over the Lehigh River (Plate 1).

The reference section of the Walcksville Member (measured section

10) is presented here to augment the type section (Klemic and others, 1963, p. 24-25), because the contact of the Walcksville with the overlying Beaverdam Run Member is exposed at the reference section. The basal beds (measured section 10, units 1 through 7) are deeply weathered; the basal contact is not exposed. The upper and lower limits of the reference section are defined by the limits of red color. There is not sufficient information to determine whether the red coloration is associated with a lithologic change such as the change between the Towamensing and Walcksville Members at the Towamensing type section.

The reference section of the Walcksville Member is 645 feet thick; 28 percent is covered. Red color predominates in about three fourths of the exposed section. The member is mainly composed of siltstone (56 percent of exposure). Forty percent of the reference section is sandstone, nearly all of which is very fine grained. Shale is a minor constituent (4 percent). Ripple marks (unit 66) and mud cracks (unit 22) were observed at the reference section, and color mottling occurs in several units (units 62, 60, 38, 27, and 6). Upward fining of grain size in beds (units 69, 65, 54, 50, and 47) was observed in the upper half of the reference section, where sandstone is a more common lithology than in the lower half.

Abrupt lateral changes in color have been observed in individual beds of the Walcksville. The most apparent color changes occur in the long exposures in the Weir Mountain syncline (Glaeser, 1967).

The thickness of the Walcksville increases considerably between the north and south side of the Lehighton anticline and across the Weir Mountain syncline. Cross section G-G′ (Plate 1) indicates that the member is about 1400 feet thick on the north side of the syncline and thickens to over 2100 feet within two miles on the south side of the syncline. This rapid thickening is due to intertonguing with the overlying Beaverdam Run Member.

The sedimentologic origin of the Walcksville will be discussed later after discussion of the two overlying members, the Beaverdam Run and the Long Run. The interpretation of the origin of the Walcksville is intimately linked with that of the Long Run and both the Walcksville and Long Run Members can best be understood in terms of their relationship to the Beaverdam Run Member which separates them in the Lehighton quadrangle.

## Beaverdam Run Member

Klemic and others (1963, p. 27-28) first defined the Beaverdam Run Member of the Catskill Formation.[1] The Beaverdam Run is a nonred unit about 600 feet thick, situated between the red beds of the underlying Walcksville Member and the red beds of the overlying Long Run Member (called Damascus Member by Klemic and others, 1963). The type section was described in cuts along the Pennsylvania Turnpike at Walcksville and was named for a creek, Beaverdam Run, which flows from the west into the Lehigh River near U.S. Route 209 between Lehighton and Jim Thorpe (Plate 1). At the type section, Klemic and others (1963) observed crinoid-stem molds, occasional brachiopods, and ball-and-pillow structures (referred to as "spheroidal masses or storm rollers" by Klemic and others). These features, in addition to the nonred color of the Beaverdam Run Member, distinguish this member from adjacent Catskill members. Moreover, the rocks of the Beaverdam Run are topographically higher than the adjacent red-bed members, the Walcksville and Long Run.

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[1] The Beaverdam Run Member is not the same as the Beaverdam Member (Middle Devonian) defined by Willard and others (1939).

Just south of Beaverdam Run, on the west side of U.S. Route 209, is a good exposure of the lower part of the Beaverdam Run Member; the upper 194 feet of the section is covered. Here, the Beaverdam Run is 963 feet thick and forms the reference section used in this report (measured section 11; Figure 101). The upper portion of the Beaverdam Run section and the contact with the overlying member are fully exposed, although not readily accessible, along the Lehigh canal on the east bank of the Lehigh River, on strike with the reference section (Plate 1). The base of the Beaverdam Run Member at the reference section is lithologically transitional with the top of the Walcksville Member, and the uppermost red bed in the Walcksville marks the boundary (measured section 11). Units 1-17 in measured section 11 are the top feet of the Walcksville Member. The reference section is predominantly siltstone (58 percent of the exposed rock), with 29 percent sandstone and 13 percent shale. All of the sandstones are very fine grained, except five percent which are fine grained. The rock units in the reference section are various hues of olive (5Y, 10Y); some are shades of green (5GY) and gray (N4 to N6).

Sandstone is confined to approximately the lower 200 feet of the reference section. Unit 52 (measured section 11) is the highest unit of sandstone without siltstone admixtures, except for rare beds (units 85, 118, and 168). Above unit 52, the predominant lithology is siltstone, some of which is classified as coarse siltstone-very fine sandstone.

Quartz pebbles (> 4 mm) and granules (2-4 mm) occur in three units of the Beaverdam Run reference section (measured section 11, units 30, 176, and 180). These fragments are dispersed in coarse siltstone (unit 180) and coarse siltstone-very fine grained sandstone. In unit 30, the quartz fragments are angular. In units 30 and 176, the quartz conglomerate occurs a few inches above the base of the units; in unit 180, the conglomerate forms the basal 4 inches of a 2-foot bed.

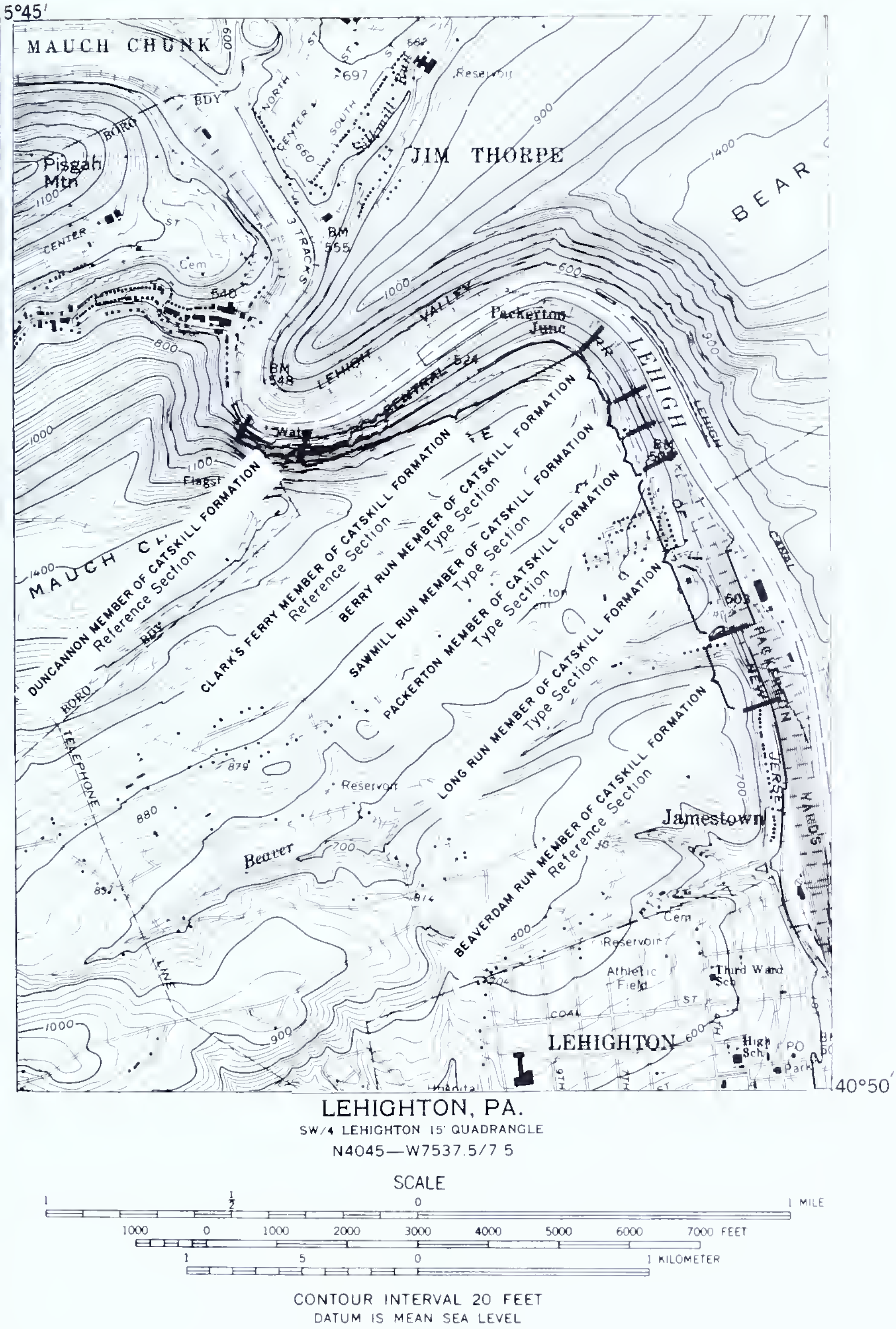
5°45′
MAUCH CHUNK
BORO
BDY
Pisgah Mtn
JIM THORPE
BEAR
Reservoir
Packerton Junc
LEHIGH VALLEY
CENTRAL
LEHIGH
3 TRACKS
DUNCANNON MEMBER OF CATSKILL FORMATION Reference Section
CLARK'S FERRY MEMBER OF CATSKILL FORMATION Reference Section
BERRY RUN MEMBER OF CATSKILL FORMATION Type Section
SAWMILL RUN MEMBER OF CATSKILL FORMATION Type Section
PACKERTON MEMBER OF CATSKILL FORMATION Type Section
LONG RUN MEMBER OF CATSKILL FORMATION Type Section
BEAVERDAM RUN MEMBER OF CATSKILL FORMATION Reference Section
MAUCH CH
TELEPHONE LINE
Beaver
Jamestown
JERSEY
YARDS
PACKERTON
Cem
Reservoir
Athletic Field
Third Ward Sch
LEHIGHTON
High Sch
PO
Park
40°50′
LEHIGHTON, PA.
SW/4 LEHIGHTON 15′ QUADRANGLE
N4045—W7537.5/7.5
SCALE
1 ½ 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

Figure 101. Location map of type or reference sections of Catskill members.

Between 300 and 600 feet above the base of the reference section, many units contain crinoid columnal plates. Single plates viewed in cross section exhibit a star-shaped lumen. Units 52 and 88 (measured section 11) are the lower and upper units in which crinoid remnants were seen. There is apparently no association of crinoid material with a specific lithology; plates occur in all lithologies of the Beaverdam Run except shale. Crinoidal material does, however, occur in layers or beds and is not scattered throughout a unit (Figure 102). Many crinoidal horizons are thin porous zones which, on close observation, reveal external molds of columnal plates. There is a wider range in occurrence of crinoid-stem plates in the type section reported by Klemic and others (1963) than in

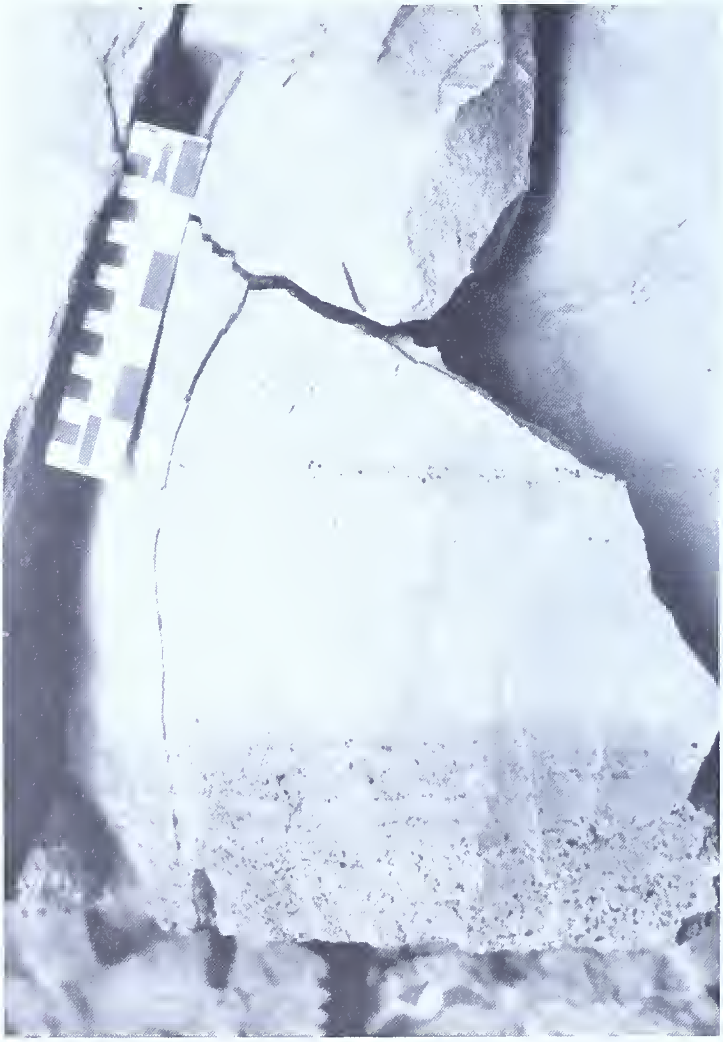

Figure 102. Segmented discs from crinoid columnals concentrated at base of massive bed of fine- to medium-grained siltstone. Unit 64, measured section 11, Beaverdam Run Member of Catskill Formation.

the reference section. Molds of crinoid-stem plates are common in float and in small outcrops of the Beaverdam Run in the Lehighton quadrangle, and are one criterion that may be used to distinguish the Beaverdam Run Member from the Trimmers Rock Formation which has a similar lithology.[1] In some float fragments, *Tentaculites* is associated with the crinoid-stem molds, although the former was not observed in either the type or reference section.

Ball-and-pillow structures occur in several units of the Beaverdam Run (measured section 11, units 26, 28, 144, 162-165). The dimensions of these ball-and-pillow structures (range 2-4 feet) are not as great as those in the Trimmers Rock Formation. Evidence of rotation, apparently due to slumping, was seen in unit 69. Figure 103 shows a thin crinoid zone in unit 69 which has been rotated 90° to the principal dip of bedding; this is a ball-and-pillow structure, composed of coarse siltstone entirely enclosed by finer siltstone. Ball-and-pillow structures are load-cast phenomena and are, in general, composed of the coarser grain sizes (coarse siltstone and very fine grained sandstone) developed on layers of siltstone and shale which surround the balls at least in part.

The thickness of the Beaverdam Run decreases dramatically between the north and south side of the Lehighton anticline and across the Weir Mountain syncline. Cross section G-G′ (Plate 1) indicates that the member is only 700 feet thick on the north side of the syncline and thins within about two miles to about 200 feet thick on the south side of the syncline. This rapid thinning is due to intertonguing with both the underlying and overlying units.

### *Sedimentologic Origin of the Beaverdam Run Member*

The massive and fissile siltstones of the Beaverdam Run Member, which include layers of crinoid columnals and load casts, are apparently similar in origin to the siltstones of the Trimmers Rock Formation. Imbrie (1964, p. 421) showed that crinoids are typically formed in shallow prodelta deposits. Although the crinoid fragments in the Beaverdam Run are in layers and are, in part, disarticulated, there is no evidence of abrasive activity during transport. These crinoids may have lived very near the site of deposition, accumulating in layers in response to current winnowing. The sedimentary structures in the Beaverdam Run are also analogous to those of prodelta deposits. However, the layering of crinoid plates, absence of graded beds, few conglomerate units with dispersed

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[1] Within the Weir Mountain syncline Klemic and others (1963, Plate 1) show in the southeastern corner of their map two patches of rock which they call Trimmers Rock Formation, surrounded by the Walcksville Member of the Catskill Formation. Actually, both patches are the Beaverdam Run Member occurring within the topographically higher portions of the Weir Mountain syncline.

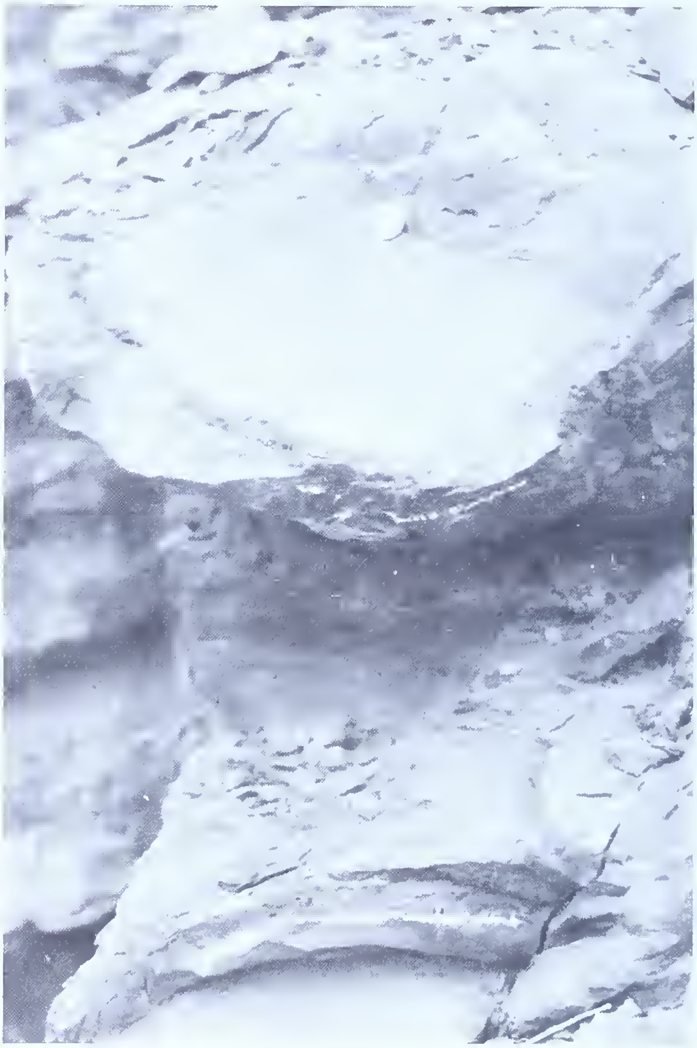

Figure 103. Rotated ball-and-pillow structure with fossil zone (crinoidal plates) oriented 90° to bedding. Unit 69, measured section 11, Beaverdam Run Member of Catskill Formation. Bedding is nearly vertical.

quartz granules and pebbles, and smaller ball-and-pillow structures indicate that the prodelta siltstones of the Beaverdam Run Member were deposited in shallower water than the Trimmers Rock prodelta siltstones. Possibly the Beaverdam Run deposits accumulated in the upper portions of the delta platform, above the slope of the prodelta, in a relatively quiet area. The abundance of crinoids suggests this type of setting, assuming that transport by current or by floating was not a significant factor in controlling their distribution.

The lower 200 feet of the Beaverdam Run probably represents a transitional nearshore sandstone between the underlying Walcksville delta-plain red beds and the overlying prodelta portion of the Beaverdam Run Member. The sandstones and siltstones of the Beaverdam Run thus indicate that transgression occurred, causing a change in deposition from underlying subaerial delta-plain deposits to nearshore (delta-front?) sands to prodelta silts and muds. This transgression represents a reversal of the regressive trend of the underlying prodelta Trimmers Rock Formation, delta-front Towamensing Member, and delta-plain Walcksville Member.

## Long Run Member

The new name, Long Run Member of the Catskill Formation, is introduced here to replace the "Damascus Member" used by Klemic and others (1963). Both terms refer to a thick red-bed succession which overlies the Beaverdam Run Member of the Catskill Formation. Willard (1936b, p. 584-585) proposed the name "Damascus" for rocks which White (1881, 1882) had called "Montrose" (Plate 1). Willard named the 400 feet of red shale around the town of Damascus, Pennsylvania, the Damascus red shale and thought it to be the lowest persistent red-bed member in the Catskill (p. 585). He also applied the name to the "3,000 feet of red beds" at the Lehigh River occurring above the rock containing Chemung fauna (i.e., the Beaverdam Run Member of this report). Willard's (1936b) correlation was based on stratigraphic position above a faunally defined horizon and was not traced by mapping to the Lehigh River using lithologic criteria. Data from a 2,165-foot borehole drilled 12 miles southwest of Damascus (White, 1882, p. 91 and 365) indicate that mainly gray sandstones and shales, and minor amounts of red beds up to 60 feet in thickness, occur in the hole. Persistence of the Damascus red shale member is not supported by the borehole data; therefore, a local name is proposed in this report for the predominantly red, 2,363-foot sequence of rocks along the west bank of the Lehigh River.

The type section is named for, and is located opposite (west of), Long Run, which drains from the east into the Lehigh River north of Weissport (Plate 1; Figure 101; measured section 12). The contact of the Long Run Member with the underlying Beaverdam Run Member is not exposed at the type section. The contact is exposed on the east bank of the Lehigh River along the canal just north of the confluence of Long Run and the Lehigh River, but the outcrop is not readily accessible for detailed description.

The top of the Long Run Member is defined as the top of the uppermost red bed in this predominantly red member. The topmost beds (measured section 12, units E193, E194, and E196) are two red shale beds capped by a thin red fine siltstone. The uppermost red siltstone is overlain by a 26-inch-thick, medium- to fine-grained, greenish- to brownish-gray sandstone interlaminated with grayish-red shale stringers, which is the base of the overlying Packerton Member. The beds above this basal unit are massive and predominantly sandstone.

The Long Run at its type section includes siltstone (57 percent) sandstone (26 percent), shale (16 percent), and conglomerate (1 percent). About 300 feet of the type section is not exposed. The most distinctive feature of the member is its red color, confined mainly to the siltstones and shales. The Long Run is mapped across the region on the basis of its typical red float and soil, as is the Walcksville Member. In the Lehighton quadrangle, the Long Run Member lies between the low hills formed by the underlying Beaverdam Run Member and the higher well-pronounced ridges formed by the overlying Packerton Member. However, the relief between the lower part of the Long Run Member and the Beaverdam Run Member is greater than between the upper part of the Long Run Member and the Packerton Member because of the increased amount of sandstone in the upper part of the Long Run. The difference in relief between the upper part of the Long Run Member and the Packerton Member is negligible, and the valley floored by the Long Run Member is asymmetrical, as seen in the stream valley of Long Run (Plate 1).

The siltstones of the Long Run Member are both massive and fissile, and are fine, medium, and coarse grained. Some are designated coarse-grained siltstone-very fine grained sandstone. The number of siltstone beds is greatest in the lower 1,400 feet of the type section. In the upper 1,000 feet, sandstone is an important component of the type section. From the base of the section upward to about 1,400 feet, siltstone and shale comprise 80 to 100 percent of the section. Above that, to the top of the section, siltstone and shale average approximately 70 percent of the section. The overall trend is toward an increase in the number of sandstone units upward, associated with an increase in both the spread in grain size and the maximum sand size.

Upward-fining sequences are a notable feature of the upper 566 feet of the Long Run Member at the type section. Elsewhere in the mapped area, the upper part of the Long Run is commonly covered by colluvium from the overlying Packerton Member. The upward-fining sequences observed in the Long Run Member are similar to those in the Walcksville Member. Because the cycles lack scoured or eroded bases, they are not considered to be similar in form or origin to the upward-fining alluvial cycles described by Allen (1964).

The base of the upward-fining sequence is defined by a planar contact overlain by a planar sandstone layer. In some cases, immediately above this planar contact, round carbonate clasts and plant fragments occur, completely unsorted, in the sandstone. The basal sandstone is commonly massive in its lower portion but has well-developed parallel-laminated planar bedding in its upper portion. Grain-size decrease generally accompanies the change from massive to planar-bedded sandstone.

Within the sandstone portion of the upward-fining sequences, colors commonly change from grays and grayish greens upward to reds and brownish reds. Above the color transition, which takes place through a zone of a few inches, grain size decreases upward to coarse siltstone and then to medium and fine siltstone, occasionally culminated by shale. The siltstone and shale portions of the Long Run upward-fining sequences are invariably red. However, the upper few inches of the topmost bed in some upward-fining sequences is gray green or yellow green just beneath the contact with the overlying sandstone bed of the next sequence. Possibly reduction of the topmost sedimentary material occurred prior to and/or during deposition of the overlying sandstone. The interface between fine siltstone or shale and the overlying sandstone may be a favorable zone for ground-water movement. The carbonaceous material observed in some of the basal beds of upward-fining successions may affect the ground water in reduction of the oxidized material (presumably an iron hydroxide) in the uppermost parts of these successions.

### *Sedimentologic Origin of the Walcksville and Long Run Members*

The Walcksville and Long Run Members have several stratigraphic and sedimentologic elements in common which permit a general interpretation of the depositional environment in which they accumulated. Factors relevant to this interpretation are:

(1) the occurrence of these two red-bed members stratigraphically above and below the marine prodelta deposits of the Beaverdam Run Member;

(2) the abundance, stratigraphic distribution, and dominant red color of the siltstones and shales in the measured sections;

(3) the presence and nature of repetitive sequences in which massive planar-bedded parallel-laminated sandstones grade upward into red siltstones;

(4) the absence of erosion or scour at the base of sandstone units that are part of repetitive sequences;

(5) the presence of carbonate nodules in three modes of occurrence: (a) near the color boundary in red (below) and green (above) siltstones of the Walcksville; (b) in the upper portion of red siltstones in which primary layering is not present, and (c) in the basal portion of massive sandstone beds. Both in the Walcksville and Long Run Members, lenticular masses containing round carbonate fragments, or the weathered-out remnants of these fragments, are found in association with gray-green shale chips and an abundance of limonite. These lenticular units occur at the base of upward-fining successions, rest upon red siltstones (gray-green where reduction has apparently occurred in the upper few inches

of the siltstone unit), and are overlain by massive sandstones which grade upward into laminated sandstones; and

(6) the gradual change in character toward the top of the Long Run Member to an increased dominance of sandstone as well as an upward increase in maximum sand-grain size and increase in spread in the sand-grain size range.

In interpreting the environment of deposition of both the Walcksville and Long Run Members, it is necessary to attempt to explain the repetitive pattern of sedimentation which seems fundamental to these red-bed successions. Once the repetitive pattern can be explained in terms of depositional mechanism (i.e., process), it is possible to relate process to morphologic setting.

The basic elements in the Walcksville and Long Run which appear to be responses to depositional process are: (1) the accumulation of massive sandstone units in which the most abundant preserved result of current action is parallel laminations (crossbedding is a minor component); (2) the upward change in grain size and color from very fine grained gray-green sandstone to evenly bedded and sometimes parallel-laminated red-gray coarse siltstone to finer red siltstones having less well preserved primary bedding; and (3) carbonate fragments, described above, which occur both as primary components of the fine red siltstones and as incorporated material at the bases of some massive sandstone units.

The following morphological setting and processes of sedimentation relate the above features to a single depositional event: a broad, relatively flat subaerial surface, where mud accumulated and which was acted upon by burrowing organisms and/or roots (presently preserved as the fine red siltstones lacking bedding), was inundated by sand-transporting floodwaters. The region was evidently of sufficiently low relief that well-established channel systems did not exist. Floodwater transport results in an essentially planar contact between the newly introduced sand and the surface over which it is transported. Low areas or depressions in the mud surface prior to flooding evidently accumulated carbonate (possibly siderite) nodules by precipitation. Evidence is still preserved of the accumulation of carbonate near the interface of ground water and air, where carbonate fragments or weathered-out zones occur in the fine red siltstones just beneath the massive sandstones. These carbonate nodules are similar to "race" described by Allen (1964). The deposits on the subaerial plain decrease in grain size upward, from very fine sands through coarse silt to finer silts that were held in suspension through the final phase of the inundation. Increase in clay-sized micas associated with the upward fining probably accounts for the color change near the sandstone-siltstone boundary. Later oxidation of these fine micas, either between floods or much later in the diagenetic process, accounts for the red coloration of the finer terrigenous material.

All products of a depositional process may not be preserved; for example, channel or overbank deposits are typically not preserved. Channel filling, scoured surfaces, and abundant crossbedding are common preserved structures of a normal fluvial system (Allen, 1964). None of these structures are present in any significant amount in the Walcksville and Long Run Members. A subaerial delta-plain environment would produce the physical features preserved in the Walcksville and Long Run Members. In addition, the stratigraphic positions of these members support the view that they are accumulations adjacent to a coastline region. The Walcksville grades up from the underlying sandstones of the Towamensing which contain abundant evidence of origin in a nearshore marine setting. The top of the Walcksville grades upward through sandstones, interpreted as delta-front deposits, at the base of the Beaverdam Run into the thick prodelta deposits of the main portion of the Beaverdam Run. The base of the Long Run represents a return to a depositional environment similar to that of the Walcksville.

Thus, the pattern of regression in the Towamensing-to-Walcksville succession was reversed to marine transgression, represented by the prodelta deposits of the Beaverdam Run Member. The Long Run Member represents a return to the previous regressive pattern; this pattern continues upward through the member, with an increasing sand content and a gradual establishment of a fluvial succession near the top.

## Packerton Member

The name "Packerton Member" is proposed for a newly designated, dominantly sandstone, ridge-forming rock unit which occurs above the Long Run Member of the Catskill Formation. The name is derived from the town of Packerton; the type section is exposed along railroad cuts on the west bank of the Lehigh River east-northeast of Packerton (Figure 101), and is 416 feet thick. The Packerton Member is also nearly fully exposed along U.S. Route 209 between the type section and the town of Packerton.

The base of the Packerton Member apparently coincides with the base of the unit called "Honesdale" by Klemic and others (1963). The Honesdale, as used by Klemic and others, extends upward stratigraphically through at least three of the members defined in this report. The use of the Honesdale as a rock-stratigraphic unit was evaluated previously; it was concluded that there is no satisfactory evidence that a physical relationship exists between sandstones at the Lehigh River and those in the original type location of the Honesdale (White, 1881).

The upper and lower boundaries of the Packerton Member occur immediately below and immediately above, respectively, the red siltstone unit at the base of the Sawmill Run Member and the red shale at the top of the underlying Long Run Member. The basal unit of the Packerton (measured section 13, unit 196) has a heterogeneous lithology and there is little persistence of laminae within the beds of the unit. In the lower 10 inches, the sandstone is fine to medium grained and green gray (5GY5/1). Shale occurs immediately above the sandstone. In the upper 16 inches of the basal unit, medium-grained, green-gray sandstone is interlaminated with gray-red (5R4/2) shale. This mixed lithology passes upward into brown-gray (5YR4/1) medium-grained sandstone. The topmost unit of the Packerton (measured section 13, unit 265) is 28 feet thick and is mainly composed of coarse- to medium-grained sandstone; a zone of fine- to very fine grained sandstone, 8 feet thick, occurs 3 feet below the top of the unit. The uppermost sandstone unit of the Packerton is overlain by nearly 55 feet of red (5R4/2) siltstones which form the base of the Sawmill Run Member.

Red color is virtually absent from the Packerton Member. Three contiguous beds (measured section 13, units 219, 220, and 221) are grayish red and consist of coarse-grained siltstone (unit 219), fine-grained siltstone (unit 220-221A), and shale (unit 221B). This grayish-red interval, which is 16 feet thick, represents a major portion of the siltstone and shale observed in the type section of the Packerton. As noted, sandstone is the dominant lithology of the Packerton and makes up 88 percent of the type section. Shale and siltstone account for 10 percent of the type section; conglomerates form the remainder.

Many of the sandstone units in the Packerton have layers or lenticular zones within them which are deeply weathered. Apparently these lenticular zones are calcareous portions of beds which have been leached by weathering. The leaching appears in beds which are in two stratigraphically separate portions of the Packerton type sections. Units 206, 209, 210, and 218 (measured section 13) represent the lower leached sandstone beds and units 239, 242, 245, 249, and 253 represent the upper group of leached beds.

The distribution of sand sizes in the Packerton Member at the type section is shown in Figure 104. This histogram is based on field descriptions of each sandstone bed. The bulk of the Packerton sandstones are fine and medium grained.

The Packerton is the first unit above the base of the Catskill Formation at the Lehigh River in which crossbedding is prominently developed. Crossbedding in the Packerton and in the overlying Catskill members is the most obvious primary sedimentary structure and is of fundamental importance in interpreting the depositional origin of these members.

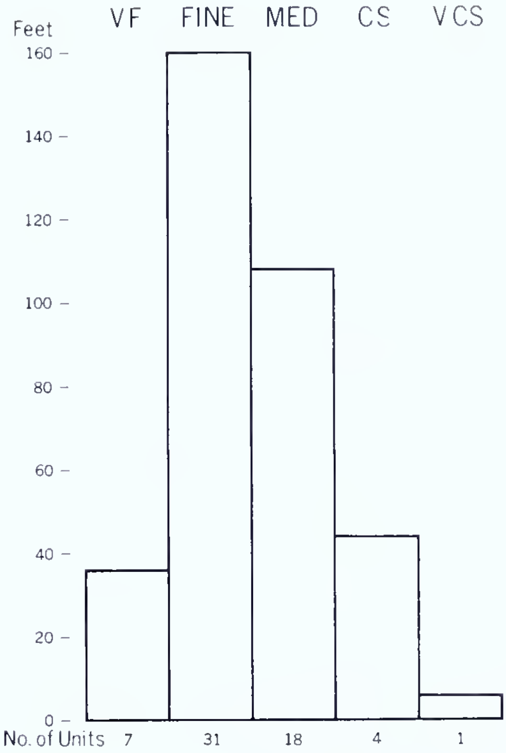

Figure 104. Size/thickness distribution of sandstones in type section of Packerton Member of Catskill Formation.

Two types of bedding occur in the Packerton; their sequential occurrence upward stratigraphically within the type section is an important clue to the nature of these deposits. The first type of bedding is a relatively steep (5°-15°) northwest-dipping foreset group of sandstone beds which are commonly parallel laminated. Dip angles represent prerotation orientations. The second type of bedding is massive or flaggy, planar, parallel-laminated, extensive sandstone beds (10 to 20 feet parallel to bedding) which in some cases dip gently (3°-8°) to the south and southeast. These gently dipping parallel-laminated beds generally truncate the steeper dipping foreset beds (Figure 105).

Lenticular zones up to 2 to 3 feet thick commonly occur below the more steeply inclined foreset crossbeds. The zones consist of gray-green shale chips and abundant limonite in a matrix of sand-sized quartz grains. In some parts of the type section, the downdip portion of the foresets merges with these lenticular zones. The zones are recognized in the field by their deeply weathered and leached appearance; somewhat fresh samples from the zones indicate that the weathering has resulted from the abundance of round carbonate fragments. The relationship of these lenses to the two bedding types in the Packerton sandstones is shown in Figure 105. Obviously this relationship is more complex in some

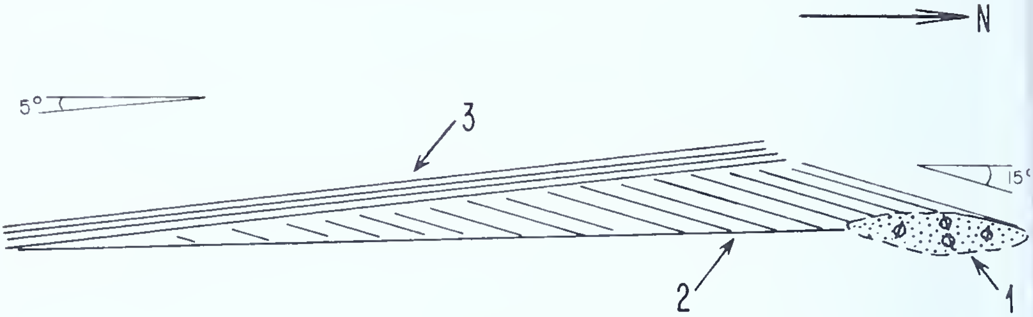

Figure 105. Bedding components in sandstones of Packerton Member of Catskill Formation. 1. Lenticular sandstone containing round carbonate fragments, gray-green shale fragments, and abundant limonite; deeply weathered. 2. Planar northwest-dipping foreset crossbeds, commonly parallel-laminated. 3. Planar, parallel-laminated beds, nearly horizontal or dipping gently to the south and southeast. Units in diagram shown in original positions prior to structural rotation.

parts of the type section than is shown in the idealized example in Figure 105. In the measured section, one of the three elements may be missing or repetition may occur, creating a complex superposition of certain elements. These deviations from the ideal example in Figure 105 are accountable in the interpretation of the depositional origin of these sandstones and will be discussed later.

The measured type section of the Packerton (measured section 13) shows the distribution of the three components which represent most of the depositional record of the member. Units 206-209 and unit 218 show the sequence and character of the three principal components. Unit 206 is a fine-grained sandstone, 17 inches thick, in which the basal 3 inches is deeply weathered and leached, containing small rust-colored pods (presumably limonite-stained shale or carbonate fragments). Planar tabular foreset beds in unit 207 dip to the northwest. Unit 207 bevels the top of unit 206, producing up to 2 feet of relief on the top surface of unit 206. Units 208 and 209 are fine-grained parallel-laminated sandstones. Unit 209 thins upward in the exposure at the expense of the overlying leached and weathered zone of the next unit, 210.

Unit 218 contains the three components of the depositional sequence: a lenticular leached zone at the base, an intermediate zone of foresets inclined 10 degrees toward the northwest, and above, flaggy, parallel-laminated, fine-grained sandstones, 6.67 feet thick. Above the sandstones, there is a weathered and leached zone at the base of the overlying unit.

Units 245-248 (measured section 13) comprise another of these three-component sequences, although the overlying leached unit (249) has parallel-laminated, fine-grained sandstone beds, a bedding feature not common to most of these more deeply weathered units. Starting with the leached zone at the top of unit 253, another three-component sequence continues upward through unit 256, although the alternation of crossbed vectors from southeast to northwest and then to southeast again in units 255 and 256 shows that this is a rather complex succession. The uppermost unit of the Packerton, unit 265, is an interesting sandstone sequence beginning with steeply northwest dipping (10°+), short, wedge-shaped foreset beds and overlain by tabular beds of planar, parallel-laminated sandstones dipping gently to the southeast. This succession of steeply northwest dipping beds followed by gently southeast dipping beds is repeated several times upward through this 30-foot unit.

The sandstone units in the Packerton type section which do not exhibit this three-component succession, such as units 212-214, 250-252, and 260-263 (measured section 13), are massive uniform sandstone units in which parallel lamination and minor crossbedding are the only observable primary sedimentary structures. In some units, flaggy bedding (1 to 4 inches thick) occurs.

The dominance of sandstone in the Packerton Member, its bedding characteristics, and the three-component succession of sandstone bedding types are the bases for interpreting the sedimentologic origin of this member. The three superjacent Catskill members, the Sawmill Run, Berry Run, and Clark's Ferry Members, have the same dominance of sandstone, bedding characteristics, and three-component successions as has been described in the Packerton. Therefore, the sedimentologic origins of all four members are considered together after the description of the Clark's Ferry Member.

## Sawmill Run Member

Immediately above the Packerton Member is a newly recognized, readily mappable valley-forming unit, here designated the Sawmill Run Member of the Catskill Formation. This name is derived from a stream, Sawmill Run, which is located in the Christmans 7½-minute quadrangle. Rocks mapped in the southern half of the Lehighton 15-minute quadrangle can be traced across Sawmill Run at the confluence of Sawmill Run and a small tributary at about the 1000-foot contour. Sevon (in press) has mapped the Sawmill Run Member as well as the other Catskill members in the northern half of the Lehighton 15-minute quadrangle.

The measured type section is in the nearly continuous outcrop along the west bank of the Lehigh River north of the exposures of the Packerton Member type section in the cuts along the former railroad (Figure 101). The contact of the Sawmill Run type section with the uppermost beds of the Packerton type section is exposed. The type section of the Sawmill Run is 424 feet thick and is described in measured section 14.

The Sawmill Run at the type section is dominantly sandstone (64 percent); siltstone (32 percent) is the only other significant component.

Nearly all of the siltstones are red. Two red siltstone beds delineate the base and top of the member. A distinctive 58-foot red siltstone and very fine grained sandstone at the top of the type section forms a mappable boundary between the Sawmill Run Member and the overlying sandstones of the Berry Run Member. A unit of red medium-grained siltstone, 55.7 feet thick, at the base forms an easily recognizable boundary between the Sawmill Run and the underlying Packerton Member. These basal and upper red beds, in addition to a 32-foot-thick red siltstone unit in the middle portion of the type section, are recognizable topographic lows on aerial photographs.

In addition to very minor amounts of shale in the type section, the Sawmill Run contains about 6.25 feet of calcareous sandstone layers. These calcareous layers are deeply leached where exposed, but fresh surfaces show numerous faces of interlocking sparry calcite which binds the rock into a very hard, massive material. Units 300, 302, 310, and thin layers in 316 (measured section 14) are calcareous sandstone. Parts of some sandstone beds in the Sawmill Run are leached; carbonate may have been present in these horizons prior to weathering (measured section 14, units 270, 271, 283, 291, 293, and 309).

Sandstones in the Sawmill Run type section have a rather limited grain-size distribution. Field classification shows that most of the sandstones are fine grained with a somewhat skewed distribution toward the very fine grain sizes (Figure 106). No coarse- or very coarse grained sandstone was observed. The histogram (Figure 106) shows the maximum sand size observed in each sandstone unit. Sand-size distribution in the Sawmill Run Member is more restricted than in the other Catskill members which are characterized by a dominance of sandstone.

Crossbedding is the most significant primary sedimentary structure in the Sawmill Run and can be used to interpret its mode of origin. The bedding character and succession of bedding types in the Sawmill Run sandstones are similar to those described in the Packerton. Wedge- and tabular-shaped northwest-dipping foreset beds are common. The foreset beds are overlain by parallel-laminated massive or flaggy units which are either horizontal or dip gently to the southeast (pre-rotation). In addition, the steeper northwest-oriented beds commonly overlie lenticular zones of weathered and leached material made up of sand-sized quartz grains, gray-green shale fragments, and abundant limonite. Evidently, granule- and small-pebble-sized carbonate fragments were originally part of the lenticular beds and have since been removed by ground water and/or weathering action. These three components—the lenticular leached zone, the steeply northwest dipping (10°±) foreset tabular- or wedge-shaped beds, and the overlying parallel-laminated sandstones—are shown in an ideal stratigraphic relationship in Figure 105. The three

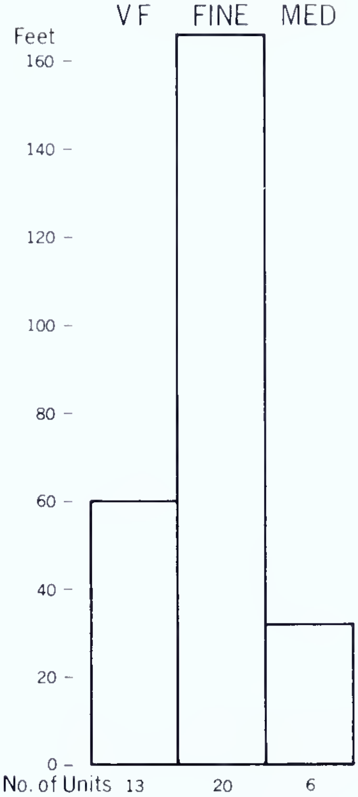

Figure 106. Size/thickness distributions of sandstones in type section of Sawmill Run Member of Catskill Formation.

components occur in this ideal sequence and in more complex sequences throughout most of the sandstone units in the Sawmill Run type section.

Several sandstone units at the Sawmill Run type section exhibit a succession of bedding types having little difference from the ideal arrangement shown in Figure 105. Units 269-273 (measured section 14) show such a succession, although the calcareous material, commonly a part of a basal lenticular bed in the sequence, is in this case incorporated into the northwest-dipping (5°) flaggy crossbeds. Plant remains are in part of a unit that is deeply weathered (basal 8 inches of unit 271). In units 272-273, above the parallel-laminated sandstones of unit 271, the beds are massive and flaggy with no evidence of crossbedding.

Units 283-285 (measured section 14) are very similar to the ideal three-component sequence except that the deeply weathered sandstones are incorporated into the northwest-dipping (10°) foreset bedding. In units 289-290 both foreset and parallel-laminated beds occur but the leached lenticular zone does not. However, the leached lithology is in the overlying unit (291). A similar relationship exists in units 304-305, the basal sandstone having festoon crossbedding. Unit 309 has all three elements (foreset beds, parallel-laminated beds and the leached zone); five repetitions of the leached calcareous fine-grained units are present near the base.

In unit 316, the three-component succession is developed with virtually no difference from the ideal sequence. Shale occurs at the base, outlining a trough form, upon which rests the overlying flaggy foreset sandstone beds. The foresets are overlain by very gently northwest dipping parallel-laminated beds. Two thin leached sparry calcite limestone units lie above the foreset beds. Associated with them are massive parallel-laminated beds, which represent the entire upper 25 feet of this sandstone unit.

In the Sawmill Run Member, as in the Packerton Member, those sandstone units which do not occur with any particular succession of bedding types are predominantly massive sandstones. Most of these massive sandstones show evidence of parallel laminations; some weather into flaggy beds. Planar bedding is characteristic of the massive sandstones, although sandstones within three-component sequences of bedding types, with the exception of most of the weathered and leached lenticular zones, are also planar bedded. There is a general absence of ripple marks and primary sedimentary structures associated with ripple migration. Because the sedimentologic origin of the Sawmill Run Member is thought to be similar to that of the underlying Packerton Member and the overlying Berry Run and Clark's Ferry Members, the discussion of the depositional environment in which these sandstone-dominated members were developed will be presented after the description of the Clark's Ferry Member.

## Berry Run Member

Immediately above the Sawmill Run Member is a distinctive, mappable rock unit dominated by crossbedded sandstones, named here the Berry Run Member of the Catskill Formation. The name "Berry Run" is taken from a stream in the northern half of the Lehighton 15-minute quadrangle (Sevon, in press), despite the fact that the measured type section is contiguous with the exposure of other Catskill members along the west bank of the Lehigh River (Figure 101) in the southern half of the Lehighton 15-minute quadrangle. Sevon (in press) has mapped the Berry Run Member from the Lehigh River exposures northeastward along Berry Run in the northern half of the Lehighton 15-minute quadrangle. No outcrop of this member occurs in Berry Run; the name is used because of the deficiency of available local names at the nearly fully exposed Upper Devonian section along the Lehigh River.

The base of the Berry Run Member is readily mappable because it is immediately above the valley-forming Sawmill Run Member; the top of the Berry Run Member can also be delineated topographically. The top is expressed by a red siltstone and fine sandstone unit which forms a less resistant surface than the conglomerate and sandstone at the base of the overlying Clark's Ferry Member. This topographic feature is subtly developed but can be seen on 1:20,000 aerial photographs.

Measured section 15 is a description of the type section of the Berry Run Member. The section is 985 feet thick and consists of sandstone (79 percent), siltstone (14 percent), shale (3 percent), and conglomerate (4 percent). Although dominated by nonred sandstone, the Berry Run contains several red fine sandstone and siltstone beds, most of which occur in the upper 175 feet of the member. Plant fragments and plant impressions were noted in several units, generally in sandstones, in the lower 260 feet of the member.

The basal unit of the Berry Run type section is an 18-inch-thick laminated very fine grained sandstone which is light-olive gray (5Y5/2). The top of the Berry Run is marked by a 24-foot red unit of very coarse grained sandstone grading up into medium-grained siltstone. Several such units, which appear to be fining upward, occur in the upper portion of the Berry Run Member. The upper contact of the member is placed at the top of the highest red fining-upward unit.

Sand-size distribution based on field descriptions of each sandstone bed in the Berry Run Member is shown in Figure 107. This histogram shows a nearly symmetrical distribution of the five sand-size categories, a feature not present in histograms (Figures 104, 106) of the other Catskill members in which sandstone is the dominant lithology. Also, the median grain size is greater in Berry Run sandstones than in the sandstones represented in Figures 104 and 106. The Berry Run is the first unit in which granule- and pebble-sized fragments, generally quartz, appear with some frequency.

Crossbeds, commonly laminated, occur in most of the sandstone units. The crossbed sets have relatively small dimensions; length-to-thickness ratio of sets is on the order of 3 to 1. This type of wedge-shaped, truncated crossbedding, common also to the underlying Sawmill Run and Packerton Members, contrasts with the geometry of crossbed sets in the overlying Clark's Ferry Member, which has length-to-thickness ratios approaching infinity.

The outcrop character of the Berry Run Member is very similar to the underlying Sawmill Run and Packerton Members. If the red siltstones were absent at the base and top of the Sawmill Run, the three members would be mapped as one unit. This similarity among the three members includes bedding types and the sequential occurrence of bedding types which has already been discussed in some detail for the two underlying members. The sandstones of the Berry Run Member show the prominent

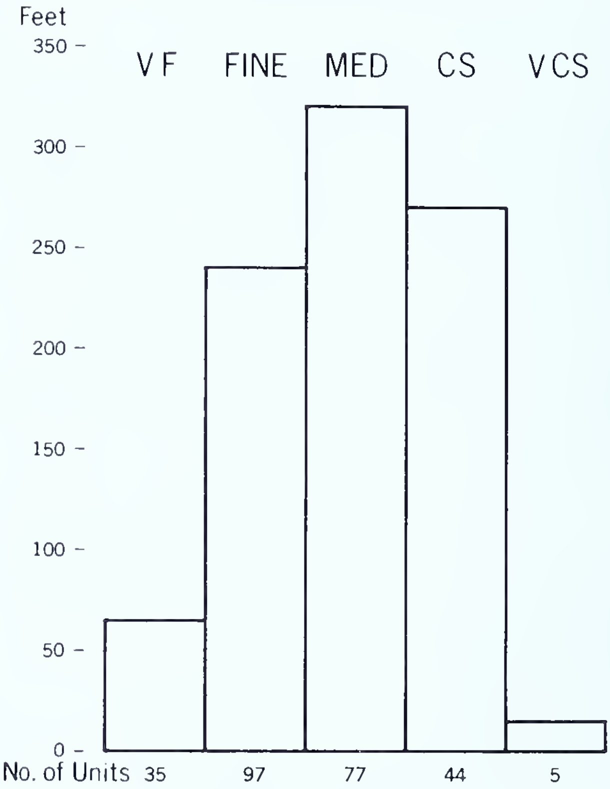

Figure 107. Size/thickness distributions of sandstones in Berry Run Member of the Catskill Formation.

set of northwest-dipping planar and flaggy beds which commonly overlie and occasionally merge with an underlying leached zone comprised of gray-green shale fragments, abundant limonite, and round carbonate fragments. Above the northwest-dipping foreset beds are planar, massive, and flaggy parallel-laminated sandstones which are either horizontal or dip gently to the south and southeast (pre-rotation).

A minor variation of the three-component succession occurs in a few sequences in the Berry Run (measured section 15, units 352, 356, 361, 368, 392, and 400). In these units, the up-dip ends of the planar northwest-dipping foreset crossbeds are bevelled by a generally smooth surface having a gentle southeast dip. Above this bevelled surface, the overlying set of crossbeds wedges and thins toward the original up-dip direction. Thus, the basal contact of these "infilling" wedges dips southeast, although commonly the parallel laminations of the wedges are horizontal or dip very gently to the northwest (pre-rotation).

In addition, relationships not observed among the three components in the two underlying members are preserved in the Berry Run. The preserved relationship is important in developing a working model of the depositional environment in which the three-component sequence can occur in repeated successions interrupted only by massive or flaggy, parallel-laminated sandstone units. Units 348 and 358 (measured section 15) show the preserved portions of individual sandstone beds in which the dip changes within the bed from northwest to southeast. The steep northwest-dipping sandstone beds change attitude across a sand-wave axis and pass into gently southeast dipping planar beds, commonly parallel laminated. Thus, units 348 and 358 are the preserved lee and stoss slopes of large sand ripples (dunes). Although other crossbedded sandstones in the Berry Run Member, as well as in the Sawmill Run and Packerton Members, do not have this crest as well preserved, the repeated occurrence of steep northwest-oriented foresets overlain by planar beds, generally parallel laminated, having either a gentle southeastward dip or no dip at all (pre-tilt), suggests this sequence is the result of migrating dunes—the stoss-side parallel-laminated sands building up and over the dune crest, burying the lee-side foreset sands of the avalanche face of the advancing dune. The persistent occurrence of the leached zone containing gray-green shale fragments, round carbonate fragments, quartz sand grains and abundant limonite below, and often intermixed with the downdip portions of the northwest-oriented foreset units, indicates that this material accumulated in the troughs between dune crests. This relationship can be seen in Figures 105 and 108.

## Clark's Ferry Member

The Clark's Ferry Member of the Catskill Formation lies immediately above the Berry Run Member and below the topmost member of the Catskill, the Duncannon Member. The Clark's Ferry Member is 904 feet thick and virtually lacks fine terrigenous detritus; shale and siltstone represent 2 percent of the measured section. Sixty-eight percent of the Clark's Ferry is sandstone; 30 percent is conglomerate. The reference

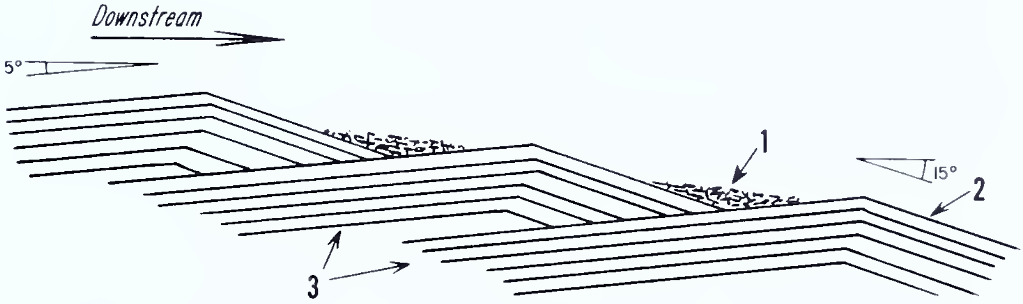

Figure 108. Cross-sectional view of dunes migrated in the downstream direction. 1. Sandy and shaly lenses containing shale and calcareous fragments in troughs between dune crests. 2. Avalanche face of dune, lee side. 3. Stoss-side parallel-laminated beds on gently dipping upstream side of dune.

section for this member in the southern half of the Lehighton 15-minute quadrangle is on the west bank of the Lehigh River in roadcuts on U.S. Route 209 just south of the town of Jim Thorpe (Figure 101). This coarse, resistant, ridge-forming unit underlies Flagstaff Mountain west of the Lehigh River and forms the south-facing bench of Bear Mountain on the east side of the river (Plate 1).

The Clark's Ferry Member of the Catskill Formation was defined by Dyson (1963, p. 26, 60-61); the type section is located in the northern half of the New Bloomfield quadrangle in central Pennsylvania. G. H. Wood, Jr. (personal commun.) has traced rocks from the type section northeastward to the ridge-forming unit at the Lehigh River.

At the reference section of the Clark's Ferry Member at the Lehigh River (measured section 16), the base occurs above the 24-foot red fine-grained sandstone and siltstone at the top of the Berry Run Member. The basal unit is a 20-foot-thick very coarse to medium-grained dark-greenish-gray (5GY4/1) sandstone.

The basal 2½ feet of the Clark's Ferry Member consists of conglomerates containing abundant well-rounded quartz pebbles. The top of the reference section is a 5-foot-thick flaggy-bedded dark-greenish-gray (5GY4/1) siltstone which lies beneath the first of a nearly continuous sequence of red units of the overlying Duncannon Member. The base of the Duncannon is a 7½-foot-thick coarse- to very coarse grained light-grayish-red (5R5/2) sandstone containing white quartz conglomerate up to 4 centimeters thick which occurs as stringers near the top of the unit.

The Clark's Ferry Member is the most conglomeratic of all Catskill members at the Lehigh River section. Conglomerate clasts are predominantly white quartz and quartzite with occasional dark fine-grained sedimentary and low-rank metamorphic rock (phyllite) fragments present. Fifty-two percent of the sandstones in the Clark's Ferry are medium grained; 35 percent are coarse grained. No very fine grained sandstone was observed.

Planar and trough cross-stratification and megaripples are common sedimentary structures in the Clark's Ferry Member. The cross-dip azimuths shown in Figure 109 have a bimodal-bipolar distribution. A principal mode lies in the interval 150° to 180°; a secondary mode having a broader spread lies between 300° and 360°. Well-preserved megaripples occur at several stratigraphic horizons within the Clark's Ferry reference section, having wavelengths up to 18 feet and crest heights up to 2 feet. Dip angles reach 25° and commonly are oriented toward the southeast. The more gently inclined planar beds are predominantly parallel laminated. Asymmetrical ripple marks occur on some megaripples. Current crescents, rib-and-furrow structures, and linguoid ripple marks also occur. Flow orientation, indicated by current crescents, is to the north-

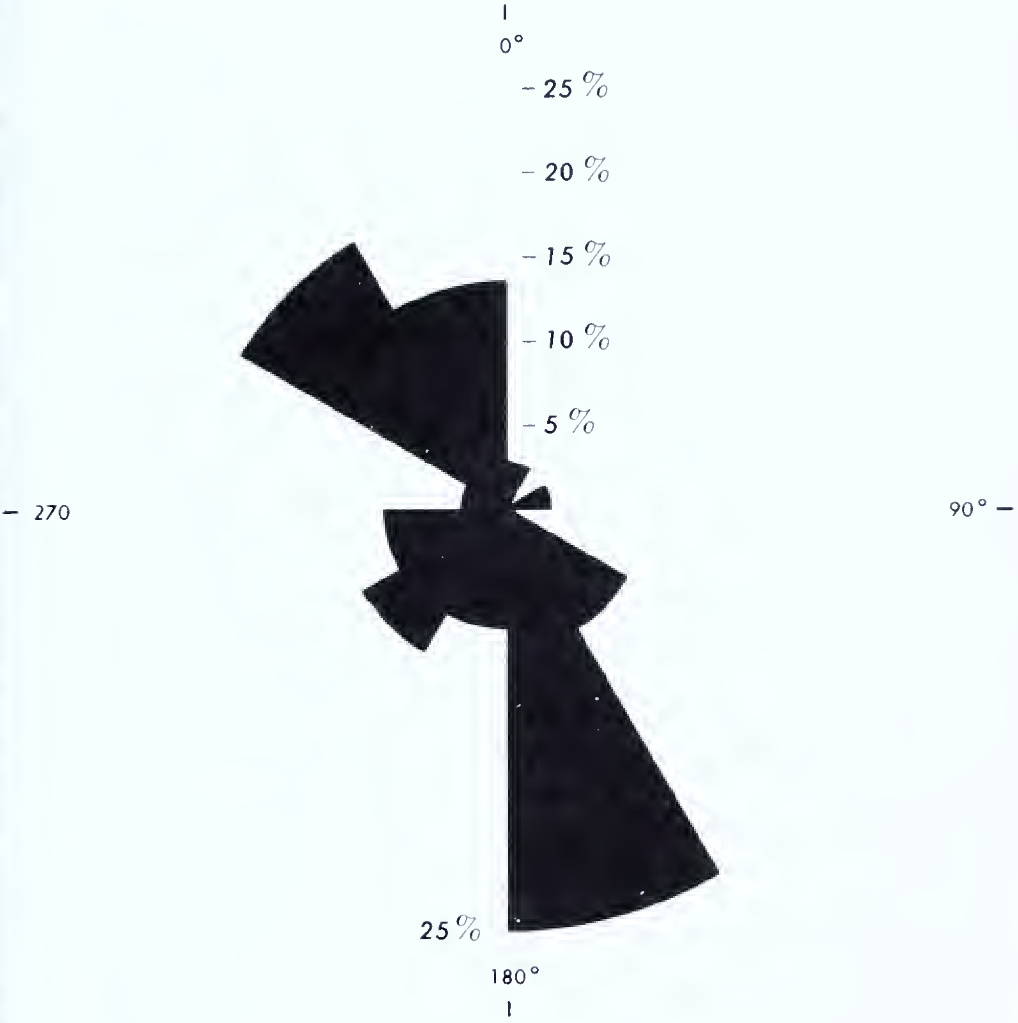

Figure 109. Distribution of crossbed azimuths (60 readings) grouped in 30° intervals. Reference section of Clark's Ferry Member of Catskill Formation.

west. Current lineations, reaching lengths of 8 to 10 feet, are common on bedding-plane surfaces. The trend of the current lineations is southeast-northwest, parallel to the dip directions of crossbedding in the Clark's Ferry.

### *Sedimentologic Origin of the Packerton, Sawmill Run, Berry Run, and Clark's Ferry Members*

The repeated occurrence of the three-component sequence of bed types, described in the sections above, is the product of migrating dunes or large ripples. The repetition and frequency of the sequences indicates a setting in which current direction and transport conditions were uniform and persistent for a considerable span of time. The small amounts of siltstone which accumulated suggest only minor interruptions of traction transport. The environment of accumulation indicated by the repetitive three-component sequences is a large braided-river system.

Because braided rivers have more than one channel, many parts of the system are in motion at any one time, even during low water. During flood stages, the entire alluvial valley in which the braided-river system occurs may be subject to the transporting influence of the river. Thus, there is normally preserved in braided-river systems only the large quantities of material carried by traction transport (sand and gravel); fine sediments are very rarely preserved, because the river retains them in suspension and transports them from the depositional area. Upon waning of floodwaters, areas above water around which the multiple braided channels flow are sand and gravel "islands" called transverse and longitudinal bars. Point bars also are present. During floods, when these bars are submerged and traction currents are strong, the bars become migrating bed forms on the river floor. The mid-channel bars build forward as sand waves; sediments are transported up the long gently upstream dipping stoss slope of the sand wave and are cascaded down the avalanche face on the lee side. Point bars are affected by downstream extension and lateral accretion during waning floods and low-water stages. The relationship of bed forms to the movement of sediment in braided rivers is described in Leopold and Wolman (1957), Doeglas (1962), Fahnestock (1963), Ore (1964), Williams and Rust (1969), and Smith (1970).

The diagram in Figure 108 shows the relationship of the three-component sequences in the Packerton, Sawmill Run, Berry Run, and Clark's Ferry Members to the processes of sediment migration in braided-river systems. The diagram is a cross-sectional view that shows, at one instant in time, dunes which have migrated downstream. The steep avalanche face (bed 2) of the migrating dunes is oriented toward the direction of flow. The shallow-dipping parallel-laminated beds (beds 3) are oriented toward the direction from which the flow is coming. Calcareous fragments and shale fragments occur in sandy lenses in the deepest portion of the troughs between dune crests (beds 1). If all components are migrated in the downstream direction in this diagram (Figure 108), the vertical succession which results is identical to the one repeated many times in the Packerton, Sawmill Run, Berry Run, and Clark's Ferry Members (Figure 110).

The diagram in Figure 108 shows the origin of both the downstream-oriented foreset beds (northwest-dipping in the four members) and the upstream gently dipping parallel-laminated beds (flat or southeast-dipping in the four members). However, the origin of the lenticular calcareous zones is only inferred. The accumulation of mud and sand in ponded areas in front of dune crests during waning flood and low-water stages is possible in a braided-river system; debris may be stranded in

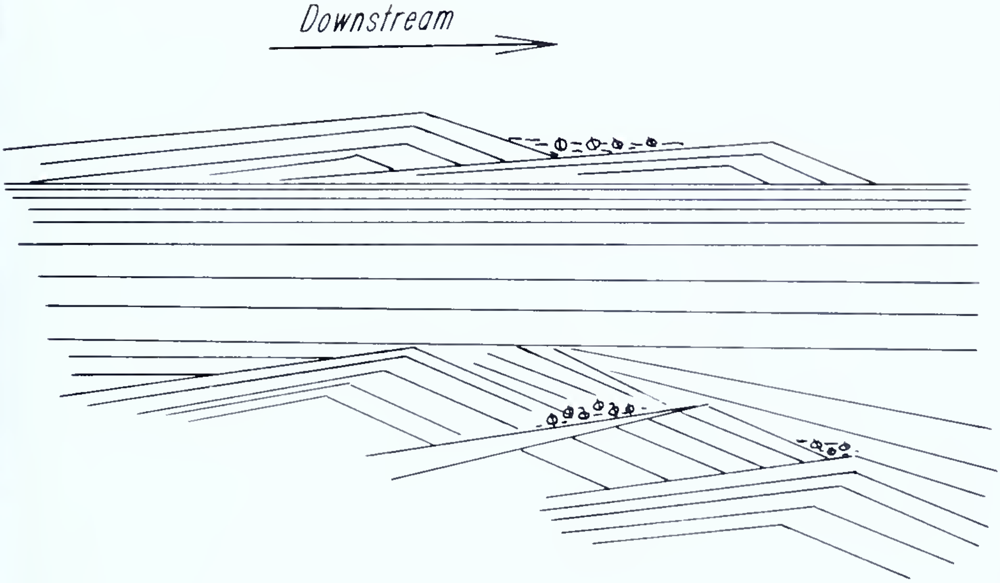

Figure 110. Complete sequence of bedding characteristics found in Packerton, Sawmill Run, Berry Run, and Clark's Ferry Members of Catskill Formation. The sequence is a product of downstream migration of dunes during waning and normal flow stages, infilling of troughs and obliteration of constructional bed forms with increase of flow rates, plane-bed development during flood (upper regime flow) stage, and return to lower regime flow constructional bed forms with waning and normal flow.

troughs on the back sides of dunes when floodwaters subside, or may be deposited in troughs in front of the dune by eddy currents. Partial or total drying of these ponded areas accounts for both the fragmental shale and the round carbonate fragments, accumulated by evaporation, called "race" or kunkur. Further detailed study of these zones is required to develop convincing evidence that these round carbonate fragments are indigenous to the depositional environment. The absence of terrigenous pebbles in association with the round carbonate fragments in any of the four sandstone-dominated members suggests that carbonate fragments are a part of the braided-river environment, possibly an important clue to the prevailing climate there.

Thus, migration of dunes and ponding between dune crests in a braided-river system account for the three-component succession repeated throughout the Packerton, Sawmill Run, Berry Run, and Clark's Ferry Members. The large segments of each of the measured type sections in which units lack any directional component and which were described as massive or flaggy, with or without parallel laminations, must also be part of the braided-river system. In these units, the absence of preserved directional properties and the repeated presence of planar beds is of great importance. These units apparently developed during river flow stages in which bed-form irregularities were obliterated. Such conditions are those of high-flow rates in which the upper flow regime prevails. Planar beds are the most common results. Such characteristics are a prevailing feature in the Clark's Ferry Member. The presence of the few steep southeast-dipping beds observed in the Clark's Ferry Member suggests that another product of upper regime flow, antidunes, is also preserved. More detailed observational data are required to verify this.

Thus, the Packerton, Sawmill Run, Berry Run, and Clark's Ferry Members are thought to represent products of two types of flow conditions in a braided-river system. The three-component sequence of bedding types is a product of lower flow regime constructional and migrating bed forms. These can be developed during waning flood stages and during normal flow conditions of the braided-river system. During periodic (seasonal?) floods in which large quantities of water moved through the alluvial valley at rates sufficiently high to obliterate constructional bed forms, thick accumulations of planar-bedded parallel-laminated sandstones, and possibly antidunes, were deposited. The thicknesses, the persistent northwest orientations of the foresets, and the sandstone dominance of these four members are evidence of a well-developed braided-river system flowing toward the northwest in a region subsiding at a sufficient rate to accommodate the nearly 3,000 feet of sandstone deposits here described.

## Duncannon Member

The uppermost member of the Catskill Formation, the Duncannon Member, is an easily recognizable unit in outcrop and in topographic expression. The member is 968 feet thick, is predominantly red, and is made up of sandstone (40 percent), siltstone (34 percent), and conglomerate (18 percent). The Duncannon occurs in roadcuts along U.S. Route 209 toward the southern limits of the town of Jim Thorpe on the west bank of the Lehigh River (Figure 101).

The type section of the Duncannon Member was defined by Dyson (1967, p. 36) and was described in sections measured by him (Dyson, 1963, p. 57-60) at Peters Mountain just south of the confluence of the Juniata River and the Susquehanna River in the northern half of the New Bloomfield 15-minute quadrangle. The type section of the Duncannon immediately overlies and is continuous with exposures of the Clark's Ferry type section. G. H. Wood, Jr. (personal commun.), in mapping Upper Devonian rocks present in the Anthracite region of Pennsylvania, has traced the Duncannon Member from the Lehighton 15-minute quadrangle to the type location in central Pennsylvania.

The Duncannon Member is lithologically distinctive because of its red color and its exceptionally well developed conglomerate units. Red color occurs in 63 percent of the thick, coarse conglomerates, in 45 percent of the massive sandstones, in 66 percent of the siltstones, and in 96 percent of the shales of the member. The Duncannon is the only Catskill member that has red conglomerates; no other member has an appreciable amount of red sandstone except the Long Run Member.

The base of the Duncannon is a thick, easily recognized conglomerate containing pebble- and granule-sized clasts of red, pink, and white quartzite and quartz set in a coarse- to very coarse grained red sandstone matrix. Five conglomerate horizons occur at the Duncannon reference section (measured section 17). Mapping suggests that one or more of these conglomerate horizons thicken laterally and contain unusually large amounts of pebbles and cobbles of varying lithology, dominantly quartz and quartzites. At the reference section, conglomerates are more common in the lower half of the member than in the upper half.

The principal sedimentary feature of the member is a succession of fining-upward cycles. At the reference section, there are 12 fining-upward cycles which, as a group, encompass nearly the total section. The fining-upward cycles have all or nearly all of the identifying features of the cycles described by Allen (1964) for the standard fluviatile cyclothem.

In the Duncannon Member, the basal bed of fining-upward cycles is commonly red conglomeratic sandstone containing eroded and incorporated chips of the underlying siltstone or shale. The basal sandstone becomes nonconglomeratic, massive, and finer grained upward, and becomes flaggy and crossbedded further upward. Crossbed vectors are all oriented toward the northwest. Interference ripples were observed in the flaggy-bedded portion of the sandstone in units 39, 42, and 62 (measured section 17). Higher in the cycle, the crossbedded red sandstone grades into red siltstone. The siltstone becomes finer and more fissile upward. Thick red fissile shale, sometimes ripple-marked and mud-cracked, occurs at the top of some fining-upward sequences. Often the basal sandstone or conglomeratic sandstone of a succeeding cycle is green or gray green, with red color beginning in overlying finer beds of the sequence. Basal scour and/or intertonguing of beds (units 64 and 67) occurs in the lower portion of some successions. In the upper part of the Duncannon Member, the fining-upward sequences lack conglomerate in the basal unit and red coloration does not dominate all lithologies.

The top of the Catskill Formation at the Lehigh River reference section is placed at the highest red siltstone in the Duncannon Member. Above the topmost red siltstone bed in the Duncannon, mixing and interfingering occur within a 239-foot zone; the characteristics of this zone, which include red shale-clast-bearing sandstones and sandstone-mudstone mixtures, are described in the following section on the Spechty Kopf Formation.

### *Sedimentologic Origin of the Duncannon Member*

The Duncannon is a fluvial deposit. The cyclic nature of the units, the coarse clastics at the bases of fining-upward cycles, the crossbedding in the coarse units of the cycles, and the shallow-water and desiccation features in the red siltstones and shales at the top of the cycles all indicate that the deposits accumulated on an alluvial plain. This alluvial plain is situated stratigraphically directly above each of the depositional environments previously described. Therefore, in its pre-rotation position, the alluvial plain prograded over the thick braided-river deposits which, in turn, rest upon delta-plain sediments. All of the subaerially formed deposits prograded a region formerly occupied by a marine environment. The entire marine and nonmarine sequence of the Catskill and Trimmers Rock Formations thus records a period of a great amount of clastic influx as well as a time of sufficient subsidence in this region to accommodate the thick accumulation of clastic deposits.

## MISSISSIPPIAN-DEVONIAN

## Spechty Kopf Formation

The Spechty Kopf Formation consists of about 548 feet of polymictic diamictite, pebbly mudstone, orthoquartzite, sandstones, and siltstones which are mapped as a single unit, but for discussion purposes are subdivided into three superposed and laterally variable lithologic components. The formation is not well exposed in the mapped area except on the east bank of the Lehigh River at Jim Thorpe (measured section 18), and mapping of the unit is dependent mainly on location of red float from the underlying Catskill Formation and conglomerate of the overlying Pocono Formation. The rocks comprising this formation do not form prominent ledges or ridges, and tend to break down into small pieces or component grains during weathering.

The Spechty Kopf Formation corresponds to the three lower lithologic components previously included in the Pocono Formation by Sevon (1969a). Use of the name Spechty Kopf is deemed desirable because:

1. Mapping by G. H. Wood, Jr., U.S. Geological Survey (personal commun.) to the southwest between the Lehigh River and Cressona, the type locality of the Beckville (lower) and Mt. Carbon (upper) Members of the Pocono Formation (Trexler and others, 1962), indicates that the basal conglomerate of the Beckville (lower) Member at Cressona is mappable into the conglomerate defined in this report as the base of the Pocono Formation.
2. The lithologies present in the Spechty Kopf Formation of this report are similar to and in many cases identical to lithologies mapped elsewhere as Spechty Kopf.

Previous workers in the mapped area have included the rocks here called Spechty Kopf in the Pocono Formation (Sevon, 1969a) and recent usage elsewhere in Pennsylvania has placed the Spechty Kopf as a member of the Pocono Formation (e.g., Dyson, 1967, p. 37; Oliver and others, 1967, p. 1006), although it was originally assigned to the Catskill Formation by Arndt and others (1962). The Spechty Kopf is given formation rank in this report because:

1. The rocks in the unit are markedly dissimilar to those of the underlying Catskill Formation and partly dissimilar from those of the overlying Pocono Formation.
2. The unit is separated from the underlying Catskill Formation by an unconformity and may be separated from the overlying Pocono Formation by an unconformity.

### *Lithologic Component 1*

Lithologic component 1 is a gradational sequence of polymictic diamictite (base), pebbly mudstone, and laminite. The sequence is 156 feet thick at Jim Thorpe and is represented by units 30-47 in measured section 18. The several lithologies apparently thin rapidly along bedding strike away from the Lehigh River.

The basal lithology of component 1 is polymictic diamictite, called tilloid in Sevon (1969a), a massive, nonbedded, unsorted rock which is about 90 feet thick at Jim Thorpe. The rock contains particles ranging in size from clay to boulders, and in thin sections (Figure 111) silt and sand grains "float" in a clay matrix. Rounded to well-rounded pebbles and cobbles of red quartzite and white quartz up to 4 inches in diameter are common in the diamictite, and a rounded boulder 2 feet in diameter occurs near the middle of the diamictite in the Jim Thorpe exposure. Pebbles of slate, sandstone, siltstone, chert, schist, and gneiss occur less frequently.

The fresh rock ranges in color from dark gray to light-olive gray, sometimes mottled with grayish red. The weathered rock has a characteristic dark-yellowish-brown or brownish-gray color. In natural outcrops, the diamictite sometimes has poor to moderately well developed slaty cleavage, and usually weathers by spalling to produce rounded rock masses. Float from this lithology is not common.

The basal contact of the diamictite is sharp. At the Jim Thorpe exposure, the diamictite overlies red shale. Other outcrops show the diamictite overlying gray sandstone. The upper contact is gradational upward through several feet into pebbly mudstone.

The pebbly mudstone is massive and structureless, brownish gray (5YR4/1) to medium-dark gray (N4), and ranges in dominant grain size from clay to coarse-grained silt. Bedding is generally absent and the rock has prominent slaty cleavage. Sand grains and rounded pebbles and cobbles up to 3 inches in diameter are scattered throughout the mudstone. The lithologies of the pebbles and cobbles are the same as in the

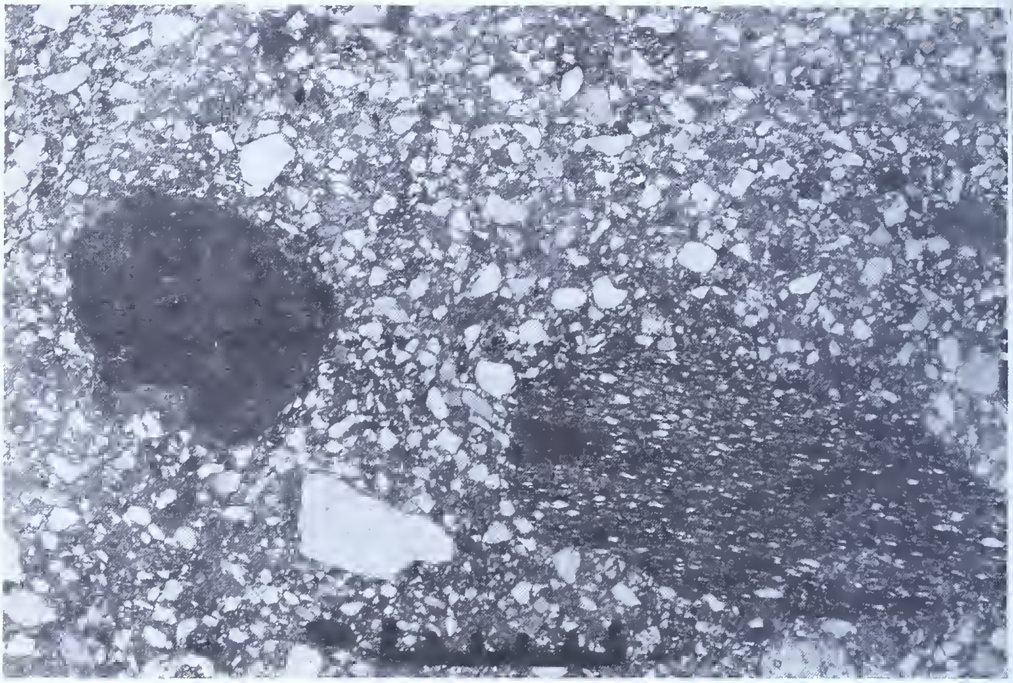

Figure 111. Thin section of polymictic diamictite from lithologic component 1 of the Spechty Kopf Formation at Jim Thorpe (unit 30, measured section 18). Dark material is clay; light particles are mainly detrital quartz. Scale is 5 mm long.

underlying diamictite, but they are not as abundant in the mudstone as in the diamictite. This unit is about 45 feet thick in the Jim Thorpe exposure. The upper 10 feet is dominantly greenish-gray (5GY6/1) shale.

The mudstone grades upward into 7½ feet of laminite characterized by clay laminae alternating with coarse-grained silt or very fine grained sand laminae. The laminae vary from ½ to 5 mm in thickness and are prominent in outcrop because of variations of value and chroma in the light-olive-gray hue (5Y5/2 or 5Y6/1 or 5Y4/2). The coarse-grained laminae show both normal and reverse grading and often have scattered sand grains or pebbles up to ½ inch in diameter along the laminae plane. Some of the pebbles have a "dropped in" appearance. The laminite at Jim Thorpe grades upward into about 12 feet of coarse-grained siltstone and medium-grained sandstone which may have load-cast structures. This contact is not exposed elsewhere in the mapped area. The sedimentology and regional distribution of these three lithologies have been discussed elsewhere by Sevon (1969b; 1969a and c; 1973b).

### *Lithologic Component 2*

Lithologic component 2 includes at least 33 feet of hard, planar-bedded, well-sorted white quartzitic sandstone (measured section 18, unit

48). The sandstone is broken by numerous bedding planes, some of which have symmetrical ripple marks. In the mapped area this rock is known only at the Jim Thorpe exposure. To the north this sandstone forms prominent ledges along the sides of the Lehigh River gorge, and contains numerous planar beds, symmetrical ripple marks, and some basal load casts. The rock contrasts with adjacent units because of its high quartz content, excellent sorting, and planar bedding. The sandstone is transitional upward into lithologic component 3.

### *Lithologic Component 3*

Lithologic component 3 forms the remainder of the formation and is about 330 feet thick at Jim Thorpe (measured section 18, units 49-159). The lithologies present in the component vary from shale to coarse-grained sandstone and the percentage distribution of these lithologies in the Jim Thorpe section is shown in Figure 112A.

The bulk of the member is made up of numerous medium-light-gray (N6) to medium-dark-gray (N4) quartzitic sandstone beds ranging from a few inches to over 20 feet in thickness. The sandstones usually have sharp contacts, but sometimes grade upward into overlying siltstones. About 60 percent of these sandstones are fine to medium grained in the Jim Thorpe section. Thin, dark-gray shale chips and rounded quartz grains up to 1 inch long occur in the lower part of some sandstone beds, but are not abundant.

The sandstones generally have poorly defined bedding planes except at boundaries with rocks of different lithology. Low-angle tabular cross-beds are sometimes present but not abundant. Some sandstones (i.e., measured section 18, units 89 and 104) have load-cast structures on their basal surfaces, but most of the beds have sharp, smooth contacts. Mica flakes occur on some bedding planes of both the sandstones and interbedded siltstones but are generally not abundant.

The sandstones are interbedded with siltstones which vary from fine to coarse grained and from dark gray (N5) to grayish orange (10YR7/4) and moderate-yellowish brown (10YR5/4) in color. These siltstones are generally massive and structureless and are mainly in beds 1 inch to 6 feet thick, although thicker beds occur in the upper part of the member (e.g., measured section 18, units 147 and 153; 31 and 8 feet thick, respectively). Nothing is known about the lateral continuity of individual beds in the mapped area. The top of the member is marked by light-olive-gray (5Y5/2) siltstone (measured section 18, unit 159) which has an irregular eroded upper surface. No fossils or plant remains were noted in the rocks of this member in the mapped area.

Because of the limited exposure and areal distribution of the Spechty Kopf in the mapped area, little can be said about its lateral variation.

However, work in adjacent areas indicates considerable thickness variation within the unit, and mapping by G. H. Wood, Jr., (U.S. Geol. Survey, personal commun., 1970) on Mauch Chunk Ridge about 5 miles west of the Lehigh River indicates an almost complete absence of the unit. The contact between the Spechty Kopf and the underlying Catskill Formation appears to be unconformable, and the origin of the basal part of the formation suggested by Sevon (1973b) requires an unconformity.

Evidence for an angular unconformity at the top of the Spechty Kopf Formation as proposed by Trexler and others (1961) has not been observed in the mapped area. However, the Spechty Kopf-Pocono contact is exposed only along the railroad track at Jim Thorpe and the existence of such an unconformity elsewhere in the map area is neither confirmed nor denied. There is evidence for an angular unconformity in the area northwest of Jim Thorpe on Broad Mountain (G.H. Wood, Jr., U.S. Geol. Survey, personal commun., 1971) ; thus, an angular unconformity may exist in the map area.

### *Microscopic Characteristics*

For purposes of convenience, the microscopic characteristics of the Spechty Kopf and Pocono Formations are treated together.

Thirty-one thin sections of Spechty Kopf and Pocono rocks from the Jim Thorpe exposure were prepared and examined. Point counts were performed on 17 of these thin sections. The following discussion treats separately several of the distinct lithologic types.

The polymictic diamictite has 30 to 40 percent matrix composed mainly of minute flakes of illite-sericite and some microcrystalline silica. The clay particles often appear oriented parallel to the margins of larger detrital grains when close to the grains, but are otherwise randomly oriented. Occasional large muscovite flakes occur. The remainder of the rock is composed mainly of silt- and sand-sized particles which float in the matrix and lack point contacts (Figure 111). Dominant sizes are very fine to fine-grained sand with small amounts of finer and coarser sizes. Particles are mainly clean, fresh, angular, strained, monocrystalline quartz grains. Some chert, siltstone, quartzite, limestone, and schist particles occur as large rounded sand grains or small rounded pebbles. Some scattered micritic calcite occurs.

The pebbly mudstone has variable quantities of matrix and silt and very fine grained sand particles. The matrix is composed of minute illite-sericite flakes and microcrystalline silica ranging from 30 to nearly 100 percent of the rock. The larger particles are the same types as those occurring in the diamictite, but are present in smaller quantity and concentrated mainly in the silt sizes.

The laminite contains alternating layers of illite-sericite clay and microcrystalline silica, and angular quartz silt and sand grains. The silt layers generally have some intermixed clay, but the clay layers generally lack silt or sand grains. The components of the rock appear to be the same as those of the underlying diamictite and pebby mudstone.

The sandstone of lithologic component 2 is essentially a quartzite. The rock is a tightly interlocked mass of monocrystalline quartz grains and interstitial fillings of microcrystalline and mega quartz. All of the quartz is strained. The original detrital grains were mainly rounded or subrounded, but secondary silicification has obscured most of the original margins. The rock is composed mainly of fine-grained sand with very little silt-sized material. A few siltstone and polycrystalline quartz grains occur as coarse grains. Contacts between grains are sutured or plane and interstitial areas are completely filled with secondary silica.

The remainder of the Spechty Kopf (lithologic component 3) and all of the Pocono Formation is represented by a variety of sandstones and conglomerates which are very similar in thin section. In general, the dominant component of these rocks is quartz, of which about 70 percent is monocrystalline and 30 percent is polycrystalline. Most of this quartz is highly strained. Some grains of siltstone and chert occur. Most of the rocks have moderate sorting and have grains predominantly in four size classes; two of the classes have nearly equal quantities of grains. Conglomeratic rocks have bimodal size distributions. Most sandstones and conglomerates contain at least 1 percent clay in the interstices and some contain up to 25 percent clay. As the amount of clay increases, the grain boundary definition increases and the degree of induration decreases. In rocks with little or no clay material, grain boundaries are often sutured, interstices are filled with secondary mega quartz or microcrystalline silica, and the module is tightly bound together. As the amount of clay increases, continuous grain contacts decrease, suturing decreases, and secondary silica decreases. Heavy mineral grains are rare in these rocks and no feldspar was observed in any thin section of Pocono rocks. Muscovite flakes occur in many slides but are not abundant.

The shales and siltstones are composed of illite-sericite clay, microcrystalline silica, and variable amounts of angular, moderately strained quartz silt grains. Some organic material, presumably plant fragments, occurs in these fine-grained rocks.

### *Sedimentology*

The origin of the Spechty Kopf rocks has been treated elsewhere by Sevon (1969a, b, and c; 1973b) and is only reviewed here. The diamictite sequence at the base is interpreted as subaqueous mudflow deposits which occurred after marine transgression onto the underlying Catskill alluvial coastal plain. The regional distribution of the diamictite (Sevon, 1969a; 1973b) suggests that deposition of that lithology was restricted to drowned alluvial channels which were deepened by erosion prior to drowning. The subaqueous mudflows may have resulted from failure and plastic flow of unconsolidated to semiconsolidated sediments along the margins of these channels, and were thus initially transverse to the general depositional slope. Such deposits and mechanisms are reported in recent submarine canyons by Stanley (1969, p. DJS-8-13-DJS-8-16) and similar subaqueous mudflow deposits are discussed by Dorreen (1951, p. 1830-31; 1834-38) and Scott (1966, p. 95). These mudflows may also have originated by erosion of glacial deposits in the source area (Sevon, 1973b). The overlying pebbly mudstone into which the diamictite grades probably represents a mixture of normal marine suspension sedimentation and subaqueous mudflow activity in which only occasional pebbles occur as clasts. The laminite represents material possibly deposited in a deltaic distal bar, but certainly representing shallowing water and increased current activity. The planar-bedded sandstones represent either tidal-sand-flat deposits or foreshore deposits. The remainder of the Spechty Kopf comprises a variety of rocks which may represent several marginal marine environments in which sandstones with low bedding inclinations were deposited. The shales may have formed in interdistributary bays, but precise environmental definitions for these rocks are not yet certain. The sequence as a whole represents regression following pre-Spechty Kopf transgression.

Regionally, a number of bay-like transgressions probably occurred between the Lehigh River and the Susquehanna River to the southwest. Between each embayment would have been a nonmarine area in which erosion may have occurred or in which contemporaneous tidal-flat or fluvial sedimentation may have occurred.

## MISSISSIPPIAN

### Pocono Formation

The Pocono Formation in the mapped area consists of 821 feet of conglomerates, crossbedded sandstones, and a few siltstones. The formation corresponds to lithologic component 4 previously discussed by Sevon (1969a) and is known almost totally from the exposure on the east bank of the Lehigh River at Jim Thorpe (measured section 18). This exposure has been recommended as the type section of the Pocono by Leonard (1953) and Sevon (1969a). The unit corresponds both lithologically and by boundary definition to the rocks mapped as the Beckville and Mt.

Carbon Members of the Pocono Formation to the southwest (Wood and others, 1969; Wood, G. H., Jr., U.S. Geol. Survey, personal commun.). These members cannot be differentiated in the mapped area. The base of the unit is marked by a massive, mappable conglomerate and the upper contact is placed at the first occurrence of red siltstone of the overlying Mauch Chunk Formation.

The formation consists predominantly of medium-grained sandstone and conglomerate (Figure 112B). The sandstones are massive and structureless, thinly bedded or crossbedded. The crossbedding ranges from long-sweeping wedges with tangential bases to steep, uniformly thick planar foreset beds. Many of the sandstones contain scattered quartz pebbles and medium-gray (N4) shale chips up to 1½ inches in diameter, as well as abundant mica flakes on bedding-plane surfaces. The contacts of the sandstone beds are usually sharp except in a few beds which grade upward into an overlying conglomerate. The beds vary from a few inches to 32 feet in thickness and average about 7 feet in thickness. The sandstones are generally quartzitic in texture, light gray (N7), and often have plant debris or plant impressions on bedding surfaces.

The conglomerates are composed almost exclusively of rounded, white quartz pebbles as large as 3 inches in diameter, with ½-inch-diameter pebbles most common. Some chert, sandstone, quartzite, and shale pebbles also occur, but they are not abundant. The quartz pebbles comprise 25 to 50 percent of most conglomerates in the member. There is a pronounced bimodality of grain-size distribution in the conglomerates with no gradation of sizes between the matrix and the pebbles. The pebbles occur in a medium- to coarse-grained sandstone matrix. The conglomerates are generally white in appearance, although the matrix sometimes has a light- to medium-gray coloration when fresh. The basal conglomerate of the unit (Figure 113) is 17 feet thick at the Jim Thorpe exposure and appears to be very persistent in the mapped area. No conglomerates occur in the 100-foot interval above the basal conglomerate, but the next 400-foot interval contains frequent conglomerates. The conglomerates vary in thickness from 5 inches to 50 feet. An average thickness is misleading since the lower 274 feet of the formation is dominated by 3 thick conglomerate beds (17, 21, and 50 feet thick), whereas in the remainder of the unit the conglomerates are all less than 4½ feet thick. All of the conglomerates in the member are massive and well indurated. The basal conglomerate appears to be the only laterally persistent unit in the formation.

Siltstones and shales form a minor part of the member and are thin, dark-gray, discontinuous units which usually contain abundant plant debris. Nothing is known about their lateral persistence in the mapped area.

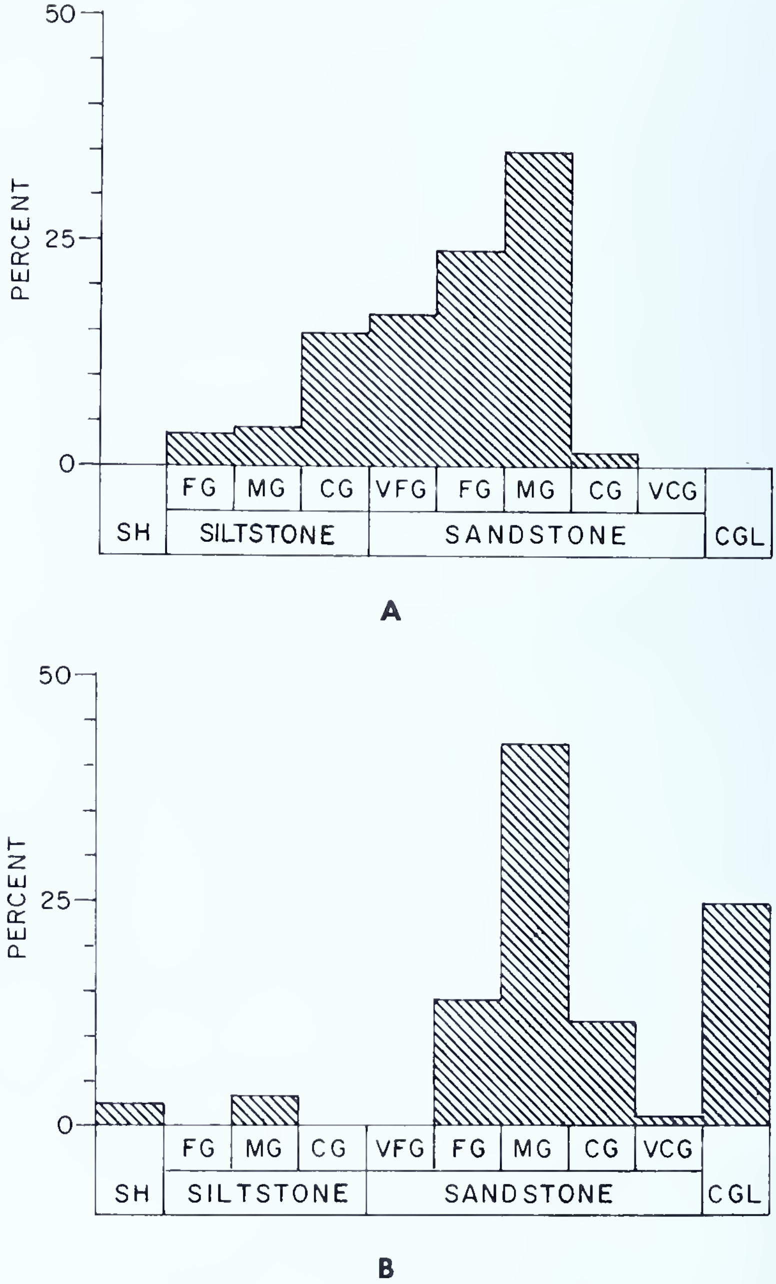

Figure 112. Distribution of grain-size modes in the Spechty Kopf and Pocono Formations in measured section 18 at Jim Thorpe, Pennsylvania. A. Spechty Kopf Formation; B. Pocono Formation.

At the top of the Pocono Formation there is a zone of interbedded red siltstones and gray sandstones. This zone forms a transition between the Pocono and Mauch Chunk Formations. The top of the Pocono is placed at the base of the first red siltstone.

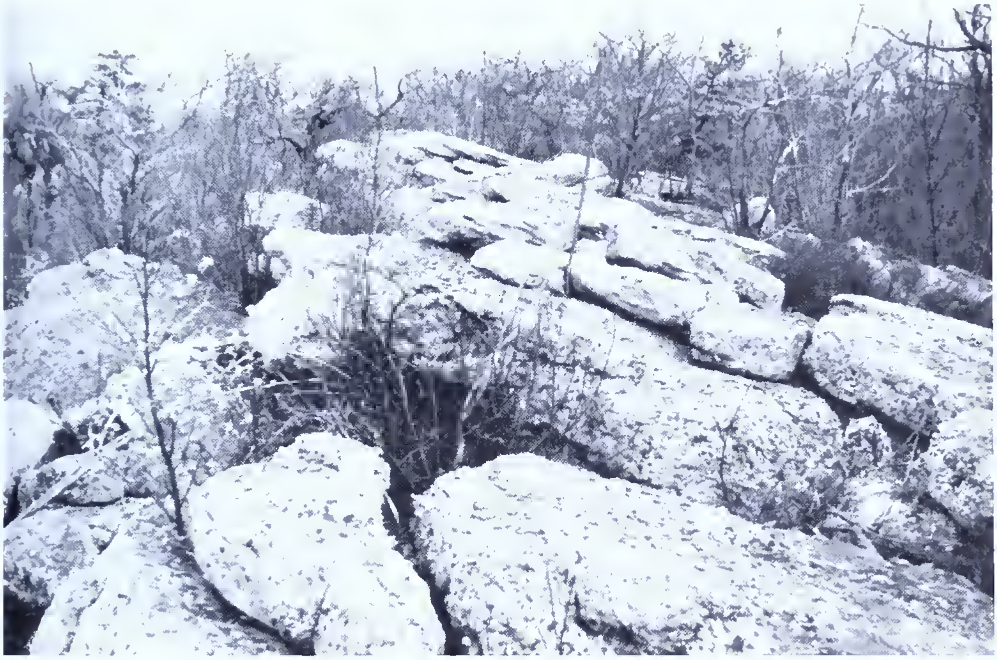

Figure 113. Basal conglomerate of the upper member of the Pocono Formation. Outcrop is on crest of Pocono Mountain about 1½ miles north of the Bear Mountain lookout tower.

*Sedimentology*

The origin of the Pocono rocks has been briefly treated by Sevon (1969a). The lithologies and bed forms appear to indicate a fluvial origin, as previously assumed by most workers (e.g., Pelletier, 1958).

## Mauch Chunk Formation

The Mauch Chunk Formation occurs only in the northwestern part of the mapped area and is made up of about 1,700 feet of grayish-red (5R4/2) and grayish-red-purple (5RP4/2) siltstones and sandstones in the lower part and about 500 feet of interbedded red siltstones and gray sandstones and conglomerates in the upper part. The formation is best exposed on the west side of U.S. Route 209 immediately north of Jim Thorpe and along the Lehigh Valley Railroad track which occurs below the level of U.S. Route 209 on the west side of the Lehigh River. This excellent exposure is the type locality of the formation and is described in measured section 19. The basal contact of the unit with the underlying Pocono Formation is best exposed along the railroad track on the east side of the Lehigh River at Jim Thorpe and is described in measured section 18. Part of the upper transition into the overlying Pottsville Formation is exposed along the west side of U.S. Route 209 about one-half mile north of the bridge over the Lehigh River at Jim Thorpe and is described in measured section 20. Scattered outcrops of the formation also occur within the town of Jim Thorpe and in some stream cuts, but, except for the above-mentioned sections, Mauch Chunk outcrops are not abundant in the mapped area.

The Mauch Chunk Formation is lithologically a much weaker unit than either the underlying Pocono Formation or the overlying Pottsville Formation. This weakness and the synclinal structure in the Jim Thorpe area have aided erosion, with the result that the Mauch Chunk occurs only in valleys in the mapped area.

The Mauch Chunk consists almost entirely of siltstones and sandstones with thin shale beds and two conglomerate beds (measured section 19, units 31 and 68). The distribution of grain sizes within the formation at the type locality (measured section 19) is shown in Figure 114. The formation is dominated by grain sizes between medium-grained silt and fine-grained sand. Color is closely related to the grain size in that grayish-red (5R4/2) colors occur almost without exception only in beds of medium-grained siltstone or finer grained beds, whereas grayish-red-purple (5RP4/2) colors occur only in beds of coarse-grained siltstone or coarser grained beds. Although most of the beds are composed of one dominant grain size, numerous beds (e.g., measured section 19, unit 61) have fining-upward sequences.

A distinct coarse zone has its base about 425 feet above the base of the formation (measured section 19, units 79-100). This zone is 242 feet

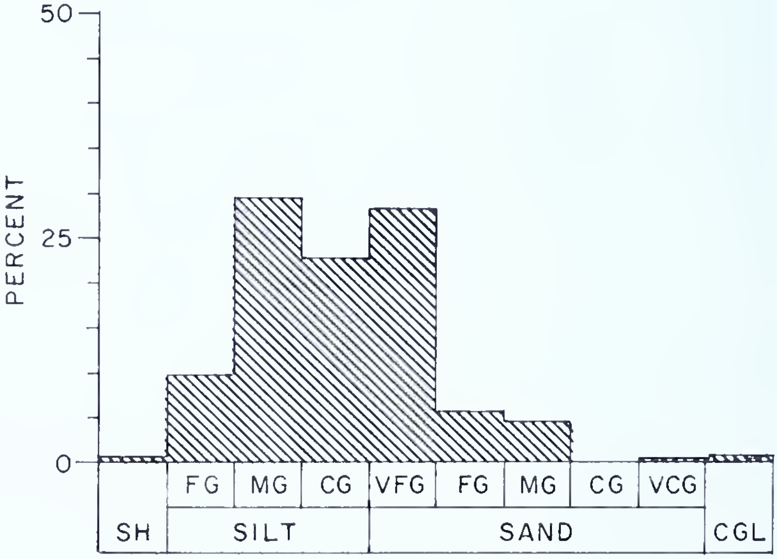

Figure 114. Distribution of grain-size modes in the Mauch Chunk Formation at the type section (measured section 19) at Jim Thorpe, Pennsylvania.

thick and is composed of 213 feet of very fine grained sandstone and 29 feet of fine-grained sandstone. The zone contains some of the most massive beds in the section and the only bed (measured section 19, unit 84) in the main part of the formation which is gray in color rather than grayish red or grayish-red purple. It is not known whether this sandstone persists laterally.

Bedding is variable within the formation; beds range from less than 1 inch to several feet in thickness. Many apparently massive beds are composed of thinner parallel-sided beds which become visible when weathered. Most beds are parallel sided and have sharp contacts, but beds occurring in channels are generally wedge shaped.

Channels are common in the Mauch Chunk, although they are seldom seen except in good exposures such as at the type locality. The channels occurring in the type section have smooth, curved shapes and range in size from 1.66 feet wide and 0.58 foot deep (measured section 19, unit 114) to over 50 feet wide and 23 feet deep (measured section 19, units 165-166). The material filling the channels is usually the same as that into which the channel is cut or is slightly finer grained. The wedge-shaped beds and the smooth plane of the channel are the main indicators of the channel.

A characteristic feature of the Mauch Chunk Formation is the occurrence of numerous concentrations of limestone masses which are white or white tinted with grayish red. These masses occur as (1) irregularly shaped nodules up to 2 inches in diameter which are more or less concentrated in zones or laterally nonpersistent beds, (2) as chaotic concentrations of small nodules or flakes, less than ¼ inch in diameter, which sometimes occur in channel-like beds and may represent channel fills, and (3) as more or less continuous bands which vary in thickness and generally are less than 2 inches thick. Zones containing these limestone masses generally have some calcareous cement. Weathering of the calcareous material produces pitted or pock-marked surfaces on many rock faces; fresh exposures of the material have visual impact because of the color contrast. The first occurrence of the limestone masses in the type section is in unit 25 (measured section 19), about 175 feet above the base of the formation. The zones of limestone masses are scattered throughout the Mauch Chunk and have no apparent association with any particular lithology or horizon. However, a zone 647 feet thick occurs between units 75 and 132 (measured section 19) which, except for a few small flakes in unit 88, has no calcareous material. This interval includes the previously discussed sandstone zone.

A variety of sedimentary structures have been observed in the rocks exposed at the type locality (measured section 19). The structures include: crossbedding and parallel laminae (e.g., units 16 and 81), sandstone dikes (unit 29), animal burrows (e.g., unit 45), asymmetrical ripple marks (e.g., unit 61) and symmetrical ripple marks (e.g., unit 93), trails and mud cracks (unit 118), and a flow structure (unit 148).

Another characteristic of the Mauch Chunk Formation is the transitional and interbedded nature of both the lower and upper contacts. Units 1 to 6 in the type locality (measured section 19) probably represent the uppermost part of the basal transition from the underlying Pocono Formation and the lower part of the transition is exposed in units 238 to 260 (measured section 18). These sections show a number of interbedded olive-gray to yellowish-gray sandstones typical of the Pocono Formation interbedded with grayish-red siltstones and shales typical of the Mauch Chunk Formation. No unusual or erosional contacts have been observed and it is assumed that the contact between the two formations does not represent any sedimentation break. For mapping purposes and in keeping with the practice of previous workers in the area, the actual Mauch Chunk base is placed at the lowest red bed, but it is not known whether the lowest red bed is represented in either of the sections mentioned above.

The upper contact is also a transition zone, and, according to Klemic and others (1963, p. 44-48), is about 500 feet thick. A detailed log of this transition zone is presented by Gault and others (1957). Very few rocks of this zone crop out in the Lehighton quadrangle, and the only described sequence is presented in measured section 20. It is probable that unit 4 of this section corresponds with the lowermost conglomerate in the section of Gault and others (1957) and thus represents the base of the transition zone. The zone consists of a series of red siltstones and shales interbedded with gray sandstones and conglomerates. There is precedence in the literature for inclusion of this transition zone in either the Mauch Chunk or the overlying Pottsville Formation. Although, sedimentologically, the first occurrence of a new lithology is the most significant aspect of the rock sequence, the mappability of the last occurrence of a red bed warrants the inclusion of the transition zone in the Mauch Chunk Formation. This procedure also maintains a unified character for the Mauch Chunk as a dominantly red unit occurring between two nonred units.

No fossils were observed in the Mauch Chunk Formation during the present investigation except for some probable log impressions.

### *Microscopic Characteristics*

Fourteen thin sections of the Mauch Chunk Formation were examined. Two of these sections were of limestones, 6 were of very fine to fine-grained sandstones, 3 were of medium- to coarse-grained siltstones, and 3 were mixtures of coarse-grained silt and very fine grained sand.

Several generalities may be made concerning the siltstones and sandstones of the sequence. The red color of the formation is derived from abundant limonite-hematite in the rock. This occurs most frequently as coatings on almost every silt or sand grain, less frequently as interstitial filling, and only occasionally as discrete grains. The amount of iron rarely exceeds 1 to 2 percent of the rock.

Micaceous matrix occurs in all of the thin sections examined in amounts ranging from 1 to about 30 percent. The micaceous matrix is mainly muscovite, but some illite-sericite also occurs. This matrix occurs as interstitial filling and occasionally as grain coatings. Much of this micaceous material is intermixed with secondary silica derived from dissolution of nearby grains. Large muscovite and biotite flakes occur in all of the slides.

Angular, strained, monocrystalline quartz forms the main part of the particulate fraction of the rocks. The margins of the grains are generally not etched and no sutured contacts were observed. The particulate fraction of all the thin sections examined is moderately well sorted and generally restricted to 3 or 4 size classes. A few chert and siltstone grains occur in the coarser sizes. Twinned feldspar grains also occur in the sequence and appear to become larger and more abundant in the upper part. Some of the feldspar grains are very fresh, some are partly sericitized, and all are angular. A few heavy mineral grains such as tourmaline, zircon, and garnet occur in most thin sections.

Calcite occurs as discrete, isolated masses of sparite scattered throughout some of the formation; the masses are often larger than the dominant grain size of the enclosing rock.

The limestone nodules are composed of a very uniform mass of micritic calcite, traversed by occasional sparite seams and rare stylolites. These limestones appear to be totally void of internal impurities.

### *Sedimentology*

Barrell (1907) attributed the Mauch Chunk rocks to deposition on a broad deltaic alluvial plain and discussed the variety of subaerial sedimentary structures present in the unit. More recently Hoque (1968) assigned fluvial and marine origins to parts of the Mauch Chunk in south-central and southwestern Pennsylvania. Previous sedimentologic work on the Mauch Chunk in the mapped area is nonexistent and present interpretations draw on knowledge of Mauch Chunk rocks from adjacent areas as well as the mapped area. The Mauch Chunk is characterized by within-bed grain-size uniformity, lateral bed continuity, variable bed thickness, planar bedding, subaerial sedimentary structures, channels, calcareous zones and limestone layers, and red color. Most of these features can result from deposition in an alluvial system and the Mauch

Chunk rocks resemble those described by Way (1968) as fluvial in origin. However, the apparent lack of fining-upward cycles, the extensive lateral continuity of the beds, and the occurrence of limestone layers are not adequately explained by any of the alluvial facies models suggested by Allen (1964, p. 163-167). The limestones may have formed in shallow freshwater ponds on an alluvial floodplain surface, whereas the matrix calcite may have formed by evaporation of water in the upper part of the ground-water table. Similar carbonate occurrences are reported by Friend and Moody-Stuart (1970).

## PENNSYLVANIAN

### Pottsville Formation

Although the Pottsville Formation represents the youngest rocks occurring in the mapped area, these rocks are not exposed within the limits of the area. The contact shown on the geologic map (Plate 1) represents an interpretation based on outcrops west of the Lehighton quadrangle, areal photographs, and the map of Klemic and others (1963). The total thickness of Pottsville rocks in the Lehighton quadrangle is not known, but probably does not exceed a few hundred feet.

The outcrops to the west and some float material in the Lehighton quadrangle suggest that the main Pottsville rocks occurring in the mapped area are conglomerates and micaceous sandstones. The conglomerates are white and comprise rounded to subangular quartz pebbles up to 2 inches in diameter set in a medium- to coarse-grained, quartz sand matrix. These conglomerates range from nearly quartzitic to moderately indurated. The sandstones are gray, highly micaceous, and range from fine to coarse grained. No information is available about the amount, thickness, or detailed nature of these rocks in the mapped area.

For more information on these rocks as they appear to the west of the mapped area, the reader is referred to Klemic and others (1963) and Smith (1895).

## QUATERNARY

Surficial deposits in the mapped area include glacial till and outwash, periglacial shale-chip rubble and boulder fields, colluvial and talus deposits, stream alluvium and floodplain deposits, landslide deposits, and man-made dumps. The distribution of these materials is shown on Plate 2 and their boundaries are also shown on Plate 1. The boundaries of these deposits generally are not as accurately located as the underlying rock-unit boundaries because (1) the time necessary for precise mapping of many of the deposits would have been greater than was deemed practical for the importance of the deposits, and (2) many of the deposits, in particular the glacial till, are thin and difficult to map because of surface creep and land alteration by man.

Surficial deposits south of Stony and Chestnut Ridges were mapped by J. B. Epstein; those north of the ridges by W. D. Sevon. The following discussion of the deposits is similarly divided where appropriate.

## Pleistocene

There have been at least three major advances of glacial ice into Pennsylvania (Leverett, 1934). In the Lehighton and Palmerton quadrangles, south of Stony and Chestnut Ridges, there is evidence for at least three and possibly four separate periods of glaciation. There are (1) outwash gravels of Wisconsinan age, (2) till and outwash of probable Illinoian age, (3) stratified drift and underlying till that is older than the probable Illinoian deposits and may be either early Illinoian in age or possibly Kansan, and (4) rare high-level gravels that may be outwash of an even older glaciation. The pre-Wisconsinan glacial history is apparently quite complex and crucial details are beyond the scope of this study. The data and interpretations are presented, however, to stimulate future detailed study.

The limit of Wisconsinan drift is shown in Figure 1, and in Gray and others (1960). The Wisconsinan terminal moraine enters eastern Pennsylvania about 21 miles east of the Palmerton quadrangle near Belvidere, New Jersey, on the Delaware River. It swings northwestward for 20 miles to near Tannersville, Pennsylvania, and then heads westward, lying about 10-13 miles north of the Palmerton quadrangle. Wisconsinan outwash extends down some of the major tributaries and trunk streams into the mapped area.

Pre-Wisconsinan drift in eastern Pennsylvania extends for several miles south of the Wisconsinan moraine, but its distribution is not completely known in eastern Pennsylvania, especially north of Blue Mountain. It is distinguished from the younger drift by its deeper weathering, redder color, general lack of constructional topography, and by its mineralogy and texture.

The textural and mineralogical makeup of many of these deposits was determined by grain-size analysis (Table 9) and X-ray diffraction studies.

### *Pre-Illinoian(?) Till*

Till believed to be older than Illinoian (?) till, because it underlies stratified drift that is older than Illinoian (?) outwash, is exposed 1 mile north of Walnutport (Figure 115) (sample locality 13, Plate 2). At least 8 feet of the till is exposed here. It is compact, poorly sorted (So = 7.2,

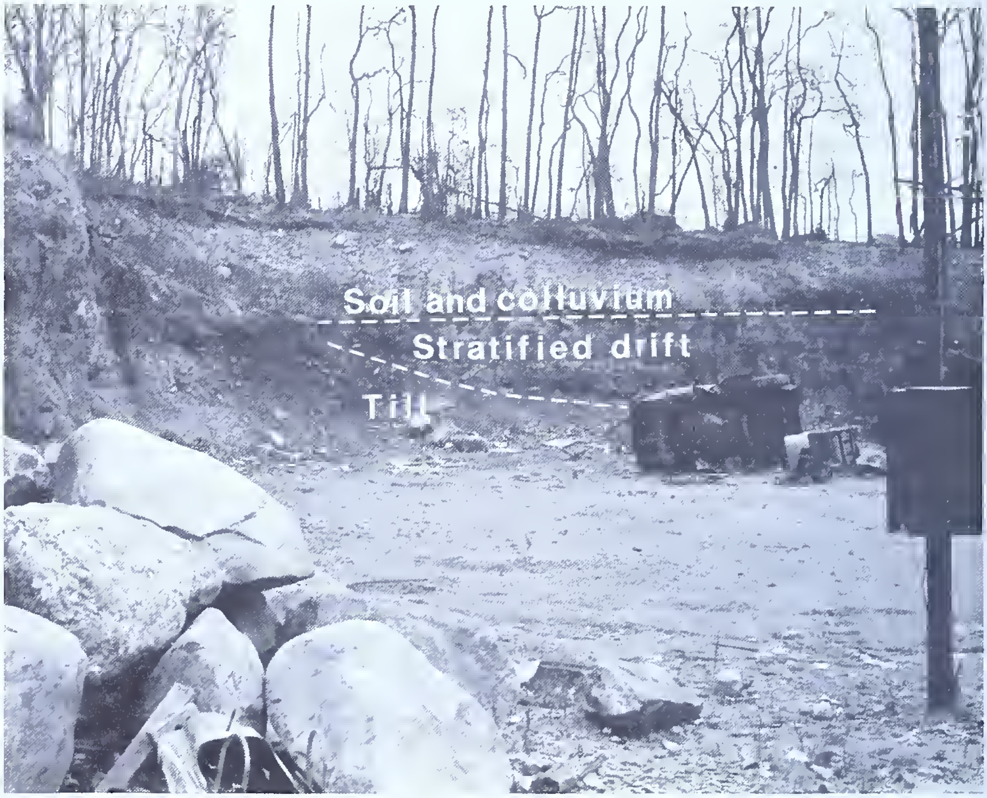

Figure 115. Pre-Illinoian(?) till and stratified drift exposed in lot behind house 1 mile north of Walnutport, sample locality 13, Plate 2. The boulders in the foreground are erratics from the till and are as much as 5 feet long, and some are partly faceted and striated. They were derived from the Shawangunk Formation at least 1.2 miles to the north. View looking south. Stratified drift thickens to the right in the direction of the Lehigh River.

Tables 10 and 11), and unstratified. Partly faceted and striated boulders of Shawangunk Formation are abundant and are as much as 5 feet long. These are in a moderate-brown (7.5YR4/4 when wet) to light-yellowish-brown (10YR6/4 when dry) pebbly muddy fine sand matrix (Table 9, sample 14). The matrix appears to be muddier than younger Illinoian(?) till (Figure 132) and has weathering characteristics similar to Illinoian(?) till described below. This till could not be mapped separately from the younger till. It may be widespread in the Lehighton and Palmerton quadrangles. Chlorite was not found in the clay-mineral fraction, but kaolinite and vermiculite were (Table 12), indicating prolonged weathering. The exact age of this till is uncertain; it may be an earlier Illinoian deposit (two Illinoian phases were described by Shepps and others, 1959, in northwestern Pennsylvania) or pre-Illinoian (Kansan?).

### *Pre-Illinoian(?) Outwash (?)*

About 9 feet of rubified horizontally stratified sand and gravel overlies the till described above (Figure 115). The deposit is coarser at the bottom. The basal bed is 0-6 feet thick (thickens to the west, i.e., to the right in Figure 115) and consists of moderate-brown (5YR4/6) cobbly medium to very coarse sand. Cobbles are subrounded to well rounded and as much as 10 inches long. This deposit is overlain by 10 inches of moderate-brown (5YR4/6) to light-brown (5YR5/6) pebbly medium to coarse sand containing rounded pebbles as much as ½ inch long and grades up into 2.5 to 5 feet of light-brown (5YR5/6) to dark-orange (5YR5/7) finely bedded medium to coarse sand. A channel sample through the three units of the stratified drift shows that the deposit is a pebbly muddy sand (sample 14, Table 9 and Figure 133). Much of the material falls in the fine and very fine sand modes (sample 14, Figure 132).

The deposit is exposed only on the east side of the Lehigh River valley in the small area shown on Plate 2. It is possibly present elsewhere in the valley under cover, and is probably the remnant of a terrace about 130 feet above the present Lehigh River (Figure 116). The deposit is distinctly redder than the younger Illinoian(?) outwash, due to more prolonged weathering and oxidation, and lies at a higher altitude. It is, therefore, older than the Illinoian(?). As with the pre-Illinoian(?) till described previously, its exact age is speculative. This stratified deposit may be either glacial outwash or an interglacial fluvial deposit. Because some cobbles are 10 inches long, requiring transportation by rather strong stream currents, the deposit may be an outwash.

A few rounded cobbles of sandstone, probably derived from the Catskill Formation, were found at an altitude of 590 feet (about 220 feet above the present Lehigh River) in Lehigh Gap. How much higher they once may have extended is not known. These are probably remnant gravels of an outwash terrace (Figure 116) that is even older than the pre-Illinoian(?) stratified drift. The age is unknown.

### *Illinoian(?) Till South of Stony and Chestnut Ridges*

Illinoian(?) till is widespread as a thin to moderately thick blanket over most of the terrain south of Blue Mountain. On Plate 2, this unit includes some older till from which it was not differentiated (see discussion of pre-Illinoian(?) till, above). No till was recognized in the valleys of Lizard or Aquashicola Creeks north of Blue Mountain. The till is best exposed in slate quarries where it caps bedrock of the Martinsburg Formation. It is generally 10-20 feet thick, but locally more than 25 feet thick. The till is compact and quite silty and clayey (see Figure 132, samples 10-12); samples are generally muddy gravels (Figure 133). Boul-

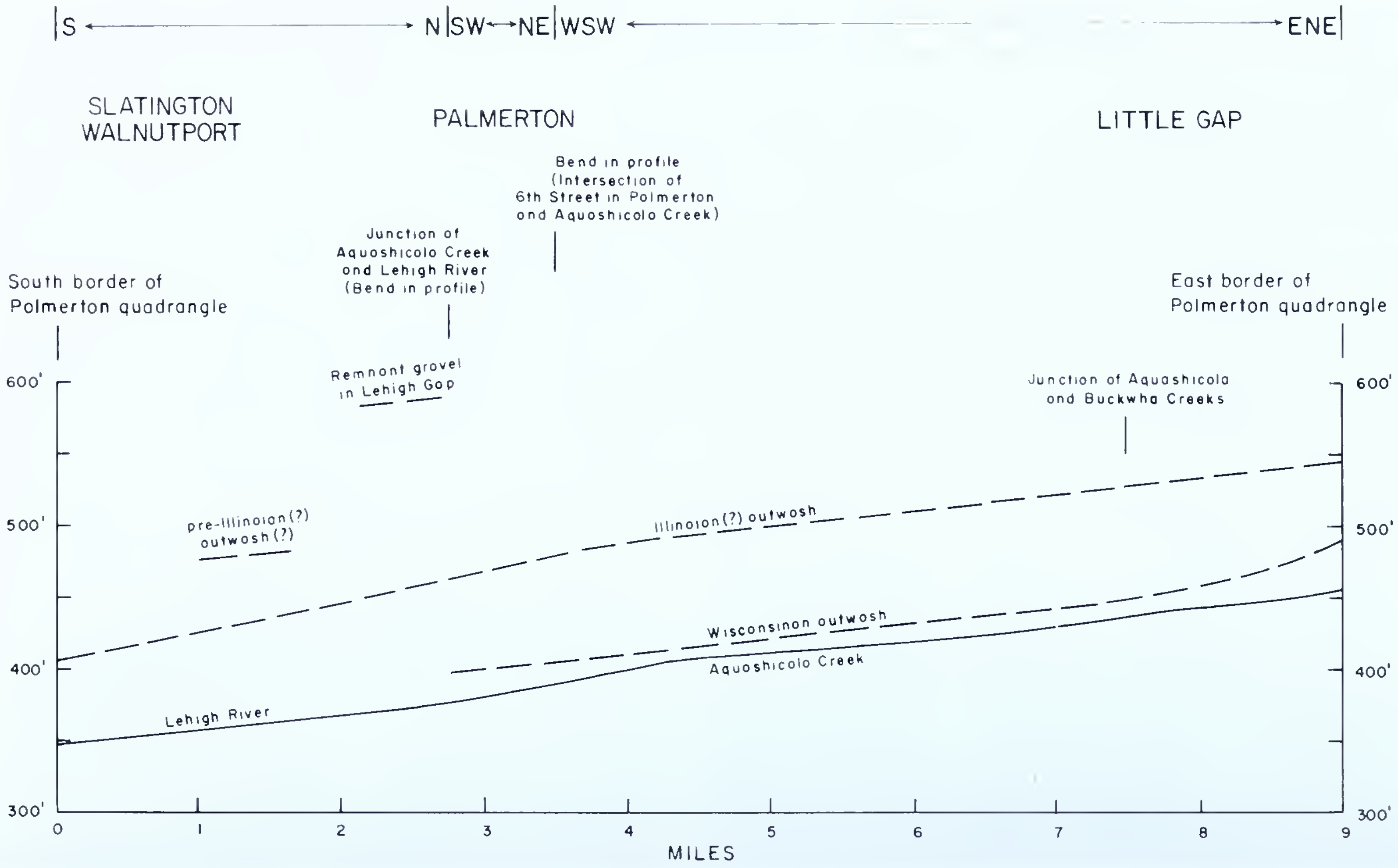

Figure 116. Reconstructed profile of outwash terraces along Aquashicola Creek and Lehigh River in the Palmerton quadrangle.

ders are abundant and may make up 5-10 percent of some deposits. They are generally fragments from the Shawangunk Formation, but some were derived from Middle Devonian and younger rocks. Boulders may reach 8 feet in length; rare erratics are as much as 20 feet long. The larger boulders are generally subangular; the smaller ones are subrounded. Glacial striae were seen on many. Weathering rinds (generally grayish-orange, 10YR7/4) on sandstones may be more than 3 inches thick. Some 6-inch-long cobbles are weathered throughout. These sandstones are broken only slightly more easily with a hammer than unweathered rocks. Weathered reddish and orangish slate chips from the underlying Martinsburg Formation are common. No limestone fragments were seen. Chert is generally leached white (N9) to light gray (N7). No fresh unleached till was found, even in exposures more than 20 feet deep. The weathered till is moderate brown (5YR4/4) and light brown (5YR5/6) to moderate-yellowish brown (10YR5/4) to dark-yellowish orange (10YR6/6), but some is moderate-reddish brown (10R4/6). The till is very poorly sorted (see Table 10); the average coefficient of sorting of three samples is 44 (Table 11).

The clay-sized minerals in the Illinoian(?) till include abundant kaolinite and vermiculite, as well as quartz and illite. Chlorite is minor (Table 12).

This till is distinctly more weathered than Wisconsinan till to the northeast (see Epstein, 1969) and is distinguished from the younger till by (1) its deeper weathering and color, (2) lack of limestone fragments, (3) leaching of chert, (4) lack of constructional topography, and (5) clay mineralogy (vermiculite and kaolinite, products of prolonged weathering, are not common in Wisconsinan till).

Leverett (1928) established that the "extramorainic fringe" deposits of earlier workers in eastern Pennsylvania were older than Wisconsinan, a view held earlier by Salisbury (1892) in New Jersey. Leverett (1934) included the area of the Lehighton and Palmerton quadrangles in a map of Pennsylvania showing the limit of Illinoian and pre-Illinoian drift sheets. Ashley (1938) believed that some of the drift mapped as Illinoian by Leverett may be early Wisconsinan in age. These deposits are referred to as Illinoian(?) in this report, because of the lack of definite correlation with the type Illinoian of the Mississippi Valley.

The Illinoian(?) till is difficult to distinguish from colluvium that lies on slopes below talus along the south slope of Blue Mountain. The colluvium weathers to the same colors as the till and contains similar gray sandstone and red beds derived from the Shawangunk on the mountain. Exposures of the colluvium are poor. For this reason, there may be considerable colluvium mapped with the Illinoian(?) till shown on Plate 2.

### *Illinoian(?) Till North of Stony and Chestnut Ridges*

Thin deposits of reddish Illinoian(?) glacial till occur in the northern third of the Lehighton quadrangle and the northwestern corner of the Palmerton quadrangle. In some places the deposits comprise only a few erratic boulders and some reddish clayey soil. A detectable topographic irregularity one mile southwest of the northeast corner of the Lehighton quadrangle may be moraine topography. Elsewhere original topographic expression of moraines has been eroded.[1] The thickness of these deposits is variable and is probably less than 10 feet in almost all areas except near Walcksville and near the Beltzville Dam. A thickness of 15 feet in the Walcksville area was observed during exploration for the Northeast Extension of the Pennsylvania Turnpike.

No fresh, unweathered Illinoian(?) till has been found in the mapped area. The weathered till is a light-brown (5YR5/6) to moderate-reddish-brown (10YR4/6), cohesive, unsorted mixture of clay, silt, sand, pebbles and boulders. The pebbles range from rounded to angular and are from locally derived shales, sandstones, and conglomerates. The boulders are generally hard quartzitic conglomerates derived from the Catskill Formation, generally the Duncannon Member. The pebbles and cobbles have a weathering rind several millimeters thick or are weathered throughout. The till contains abundant clay, and the material is often brick hard when dry. This till was used as impermeable core for the Beltzville Dam.

Deeply weathered clay-rich till is exposed in a roadside borrow pit on the west edge of Lehighton (measured section 21). A semiquantitative X-ray analysis (performed by mineralogists of the Pennsylvania Geological Survey) of clay-sized material from this exposure shows the following:

| | |
|---|---|
| Chlorite-vermiculite-montmorillonite | 9 percent |
| Muscovite | 35 |
| Kaolinite | 0 |
| Quartz | 52 |
| Feldspar | Trace |

Recognition of the till is difficult in some places because most of it has been removed by erosion. In areas underlain by the Mahantango Formation the surface often contains abundant siltstone chips that are dominantly grayish orange (10YR7/4) as well as pale-yellowish orange (10YR8/6), light red (5R6/6), and moderate pink (5R7/4). These chips and a few small pebbles and some boulders piled along the margins of cultivated fields are often all that indicates the former presence of the till.

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[1] Reevaluation of these deposits by Sevon after this report was in press indicates that all deposits in Long Run valley mapped as Illinoian are Early Wisconsinan in age (Sevon, 1974).

In some areas iron oxides from the till have stained the underlying Mahantango shale reddish orange.

All Illinoian(?) glacial material in the area lies south of outcrops of thick Catskill conglomerates. Thus glacial materials are easily recognized because most of the larger erratics are conglomerates.

### *Illinoian(?) Outwash South of Stony and Chestnut Ridges*

Deeply weathered moderate-brown (5YR4/4) to light-brown (5YR5/6) and dark-yellowish-brown (10YR4/2) to dark-yellowish-orange (10YR6/6) sand and gravel underlies flat terraces and gently sloping surfaces along the Lehigh River and Aquashicola Creek. The cobbles in this outwash are rounded and are generally 6-8 inches long, but larger boulders are present, especially south of Blue Mountain. Weathering rinds on the cobbles are at least ½ inch thick; some cobbles have rinds at least 3 inches thick. Chert particles are leached white (N9) to light gray (N7). Although till was undoubtedly derived from Silurian and Devonian limestones, no limestone fragments were seen; presumably they have been completely removed by leaching.

The outwash probably averages less than 20 feet in thickness; the greatest thickness recorded was 26 feet in a water well for the American Nickeloid Company in the northwest section of Walnutport.

In many places the rounded gravels of the Illinoian(?) outwash are incorporated in weathered colluvium underlying gentle to moderate slopes, especially in the valley of Aquashicola Creek east of Palmerton. Although they have been modified, these Illinoian(?) outwash deposits were mapped because their position aids interpretation of the glacial history of the area. An excellent example of this type of deposit may be seen in fields south of Aquashicola Creek and southeast of the village of Little Gap. Rounded Ridgeley and Palmerton boulders are as long as 1 foot. These are imbedded in light-brown (5YR5/6) to grayish-orange (10YR7/4) and gray clay and silt colluvium with bedding parallel to the slope. In many other places, the outwash gravels are mixed with subangular to angular boulders of colluvium many feet long. The mixed colluvium and outwash contains more silt and clay than the outwash (samples 8 and 9, Table 9, and Figures 132 and 133). Sorting is poor (Table 10), averaging 25 for two samples analyzed (Table 11).

The terrace form is well developed in and around Palmerton, and the outwash consists of muddy sandy cobble gravel (samples 6 and 7, Table 9; Figure 133). A small channel is cut into the Shawangunk Formation and Bloomsburg Red Beds along Pa. Route 248 (sample locality 8). Here, rounded boulders are as long as 1.5 feet. The following is a count of 100 pebbles from this locality.

| Pebble lithology | Percent |
|---|---|
| Greenish sandstone (Middle Devonian and younger) | 34 |
| Red sandstone (Catskill or Bloomsburg) | 10 |
| Orangish sandstone (Oriskany and Palmerton) | 4 |
| Gray siltstone and shale (Schoharie-Esopus, Marcellus, and Mahantango) | 21 |
| Red siltstone and shale (Bloomsburg and Catskill) | 5 |
| Chert (New Scotland or Buttermilk Falls) | 5 |
| Yellowish shale and siltstone (probably Poxono Island) | 21 |

Illinoian(?) outwash is exposed along the Central Railroad of New Jersey one-half mile north of Walnutport and in pits of the American Nickeloid Company in Walnutport. The matrix of these deposits is medium to very coarse sand (apparently more sandy than north of Blue Mountain) and many rounded boulders are 1-2 feet long. A few water-worn boulders are more than 6 feet long (Figure 117; also see Miller and others, 1939, pl. 17B, p. 288).

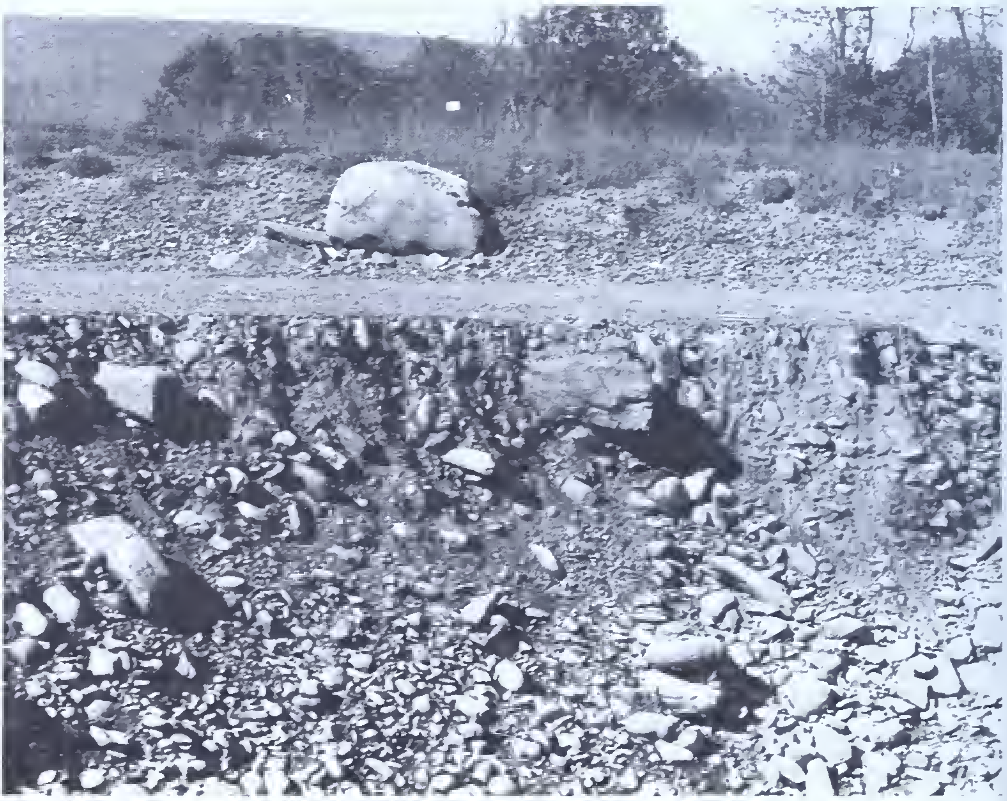

Figure 117. Coarse gravel and sand in Illinoian(?) outwash in pit of American Nickeloid Company, Walnutport. The large water-worn boulder above the pit is more than 6 feet long. Many boulders are more than 1 foot long. The outwash is about 10 feet thick at this locality.

A longitudinal profile of the Illinoian(?) outwash terrace is shown in Figure 116. The terrace is about 60-90 feet above the present Lehigh River and Aquashicola Creek. The upper limits of outwash may be slightly inaccurate because of several mapping difficulties. These include: mixing of outwash with colluvium, possible mixing with even older stratified drift, and poor exposure.

The clay-sized minerals in the Illinoian(?) outwash include illite, quartz, chlorite, vermiculite, and kaolinite (Table 12).

### *Illinoian(?) Outwash North of Stony and Chestnut Ridges*

Deposits of reddish-orange Illinoian(?) outwash gravels in terraces are extensive along Pohopoco Creek[1] and in a few places along the Lehigh River.

The outwash is mostly unconsolidated, poorly sorted, moderate-brown (5YR3/4) to moderate-reddish-brown (10R4/4 or 10R4/6), sandy gravel with rounded pebbles of varying lithologies. Almost all pebbles are deeply weathered, having weathering rinds up to 1 cm thick. Many disintegrate readily with only moderate pressure. The pebbles and boulders are derived mainly from Catskill sandstones and conglomerates. Only the small pebble fraction contains abundant locally derived material (mostly Mahantango shale). The texture of the outwash varies from deposit to deposit, but most deposits have pebbles 4 to 6 inches in diameter. Little is known about vertical and lateral continuity of individual beds within the outwash gravels, but observations suggest considerable variation.

Red clay was exposed in several deep exploration pits in the terraces along Pohopoco Creek, but nothing is known of its areal extent or its lateral continuity. The clay is approximately reddish brown (10R4/4), massive, and cohesive. Two semiquantitative X-ray analyses of this clay from two pits about 0.6 mile west of Pine Run follow.

| | A | B |
|---|---|---|
| Chlorite-vermiculite-montmorillonite | 1 percent | 6 percent |
| Muscovite | 50 | 41 |
| Kaolinite | 1 | 11 |
| Quartz | 34 | 39 |
| Feldspar | 1 | Trace |

Beds of sand also occur in the outwash, but very little is known about their variability or extent. Most of the outwash is probably 10 to 20 feet thick and the thickest known deposit, exposed at the dam site during the construction of the Beltzville Dam, is over 80 feet thick. Exploration work for the Beltzville Dam (U.S. Army Corps of Engineers, 1965) indicates that this thick deposit fills a former channel of Pohopoco Creek and that the bedrock high between the bottom of the old channel and the present channel has a relief of about 10 feet.

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[1] Reevaluation of some of these deposits by Sevon (1974) after this report was in press indicates that some or all of these deposits may be Early Wisconsinan in age.

### *Wisconsinan Outwash*

Aquashicola Creek flows in a flat-floored valley 1,000 to 1,500 feet wide. Except for the thin fine alluvium along the creek, the valley is underlain by moderate-brown (5YR4/4) to moderate-yellowish-brown (10YR5/4) muddy sandy cobble gravel (samples 4 and 5, Table 9, Figure 133). The sand is generally medium to very coarse (Figure 132, samples 4 and 5). Sorting is generally good (sample 3, Table 10). The poor sorting of sample 4 in Table 10 is mostly due to collecting of several better sorted thin beds of different texture. There are few good exposures of this outwash, but the superintendent at the sewage disposal plant in Palmerton noted that during construction, the upper 15 feet of the deposit was exposed and consisted of horizontally stratified sand and gravel. Some of the sand is now used for filter in the plant. The boulders from this locality are well rounded to subrounded and are as much as 2.5 feet long. Most of these boulders have only a paper-thin weathering rind. Chert fragments are generally dark gray (N3). Some cherty limestone was noted. A count of 100 pebbles at the Palmerton sewage plant follows.

| Pebble lithology | Percent |
|---|---|
| Greenish sandstone (Middle Devonian and younger) | 35 |
| Red sandstone (Catskill or Bloomsburg) | 14 |
| Orangish sandstone (Decker, Oriskany, and Palmerton) | 9 |
| Gray siltstone and shale (Schoharie-Esopus, Marcellus, and Mahantango) | 15 |
| Red siltstone and shale (Bloomsburg or Catskill) | 4 |
| Chert and cherty limestone (New Scotland, Oriskany, and Buttermilk Falls) | 16 |
| Yellowish shale (Poxono Island) | 4 |
| Gray quartzite (Shawangunk) | 3 |

The pebble composition of the Wisconsinan outwash is remarkably similar to that of the Illinoian(?) outwash. Some of the pebbles in the Wisconsinan outwash are rotted, and some chert is white. Perhaps these were derived from older drift.

The Wisconsinan outwash can be distinguished from the older terrace gravels by its color and weathering characteristics, general lack of deep weathering rinds on cobbles and boulders, dark-gray color of the chert, presence of limestone, and lower height (about 10 feet) above the present creek (Figure 116). The clay mineralogy is also distinctive in that chlorite is abundant (Table 12). This is similar to the mineralogy of Wisconsinan till and stratified drift northeast of the Wisconsinan terminal moraine in the Stroudsburg, Pennsylvania, area (Epstein, 1969). The minor amounts of kaolinite and vermiculite in the outwash may be the result of reworking from older deposits.

The outwash may be rather thick in the center of the valley of Aquashicola Creek. In the two exploratory wells drilled by the U.S. Army Corps of Engineers south of Walkton (see Plate 1), brown clayey sand and gravel was 66 feet thick in the northern one (bedrock encountered at an altitude of 366 feet) and 49 feet thick in the southern one (bedrock encountered at an altitude of 377 fee'). The altitude of bedrock in the valley does not conform to the expected equilibrium profile for this stream. One mile to the south of Lehigh Gap, 5.5 miles down valley of the wells, ribs of Martinsburg bedrock are in the Lehigh River at an altitude of 360 feet. Bedrock is also exposed in Aquashicola Creek at an altitude of about 390 feet just south of the sewage disposal plant. It appears, therefore, that the present course of Aquashicola Creek south of Palmerton was established in Wisconsinan time (the Wisconsinan outwash terrace is found there), some of the drift in the wells at Walkton is pre-Wisconsinan in age, the main course of the creek during Illinoian(?) time paralleled Delaware Avenue in Palmerton, and there may have been deepening of the Aquashicola channel by glacial scouring during Illinoian(?) time. This cannot be currently proven because no Illinoian(?) till has been recognized in the valley. The Lehigh River was a major channelway throughout the Pleistocene because stream terraces of many ages are found there. Clearly, the drainage evolution in the Lehighton and Palmerton quadrangles has been complex.

A Wisconsinan outwash terrace was not seen along the Lehigh River south of Blue Mountain. The terrace ends abruptly below the confluence of Aquashicola Creek and the Lehigh River, so the present Lehigh south of Blue Mountain has completely removed the outwash. Gravels in the bed of the river south of Blue Mountain and below the alluvium are all that remain of the outwash.

The outwash is present along Aquashicola Creek for one-half mile east of the Palmerton quadrangle and is missing in the narrow valley for 6.5 miles to the northeast. It is present again in the valley southwest of Saylorsburg, Pennsylvania (J. B. Epstein and G. G. Connally, unpub. data).

### *Shale-Chip Rubble*

Deposits of shale-chip rubble are along the road between Harrity and Big Creek, on the east side of the rounded hill one-half mile south of East Weissport, along Pa. Route 443 at Lehighton (Figure 31) and north of Ashfield. Similar deposits probably exist elsewhere in the area. The rubble comprises chips of Mahantango shale mainly ¼ to 1½ inches long and less than ½ inch thick. The flakes are generally imbricated, dip downslope, and lie nearly parallel to the upper surface (Figure 118). Some of these deposits have convolute bedding in the uppermost part of the deposit.

The rubble is uncompacted and lacks clay or silt matrix, but most of the flakes have coatings of clay. Some ¼- to ½-inch-thick layers of clay and silt lie parallel to the upper surface. The sorting of the shale chips is generally very good, but large pieces of shale, including plates up to 10 inches long, have been observed.

The rubble occurs at the base of slopes underlain by Mahantango shale. The rubble was derived from the rock outcrop by frost riving and accumulated as a talus at the base of the slope. The resulting deposit is wedge shaped, with the thickest part at the base, the thinnest at the top, and a variable thickness in between, depending upon the configuration of the bedrock surface. No total thickness was determinable for any of the deposits. The deposit south of East Weissport is more than 20 feet thick, but deposits along Pohopoco Creek are probably much thinner. Only those deposits exposed in road or stream cuts and quarrying operations have been mapped. Other deposits of rubble probably exist, but the vegetated surface of such a deposit is not readily distinguishable from

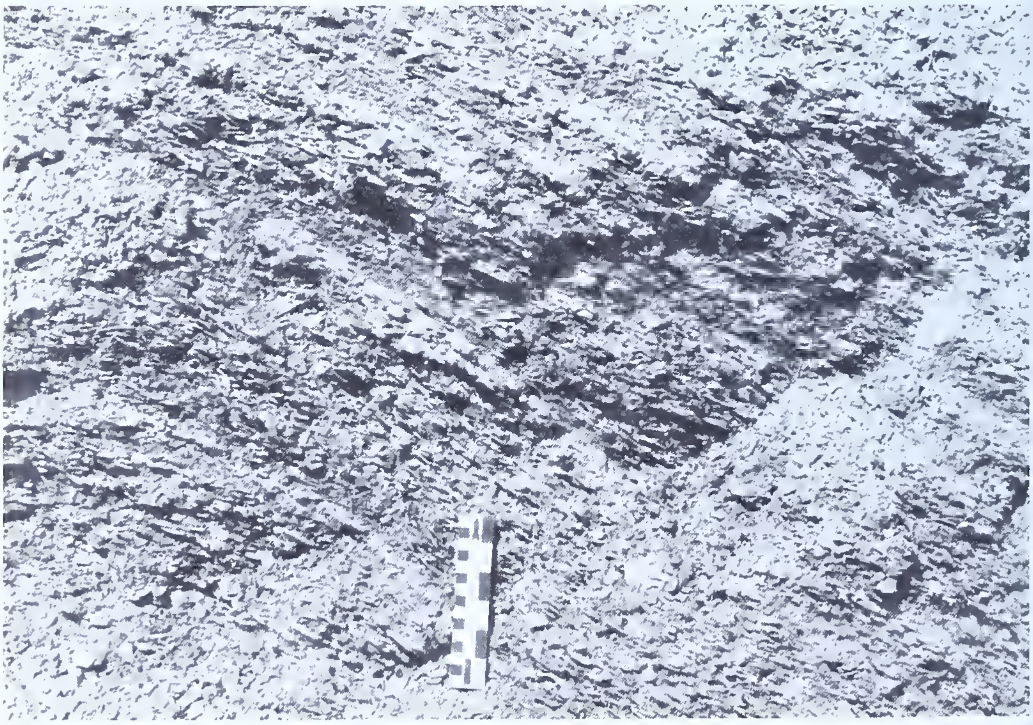


Figure 118. Shale-chip rubble deposit a half mile east of Harrity along road to Beltzville Reservoir. Note imbrication and bedding.

a surface underlain by Mahantango bedrock, and unexposed rubble deposits were not augered. Some rubble deposits mask complex sequences of older surficial deposits (Figure 119).

In the quarry of the Penn Big Bed Slate Company, 6,000 feet west of Rextown and 300 feet south of the Lehighton quadrangle, in the Slatedale quadrangle, shale-chip rubble or gravel underlies 29 feet of Illinoian(?) drift (Figure 2). The rubble consists of 14 feet of predominantly dark-yellowish-orange (10YR6/6) weathered platy fragments of Martinsburg slates that are 1/4 to 6 inches long and 1/16 to 1/4 inch thick. These lie in a silt and clay matrix. The plates generally lie horizontally. Scattered throughout are pebbles and cobbles 1/4 to 6 inches long of subrounded quartzite from the Shawangunk Formation and other minor red beds. The unit contains rare angular quartzite boulders as much as 14 inches long. The gravel was probably emplaced by periglacial solifluction from

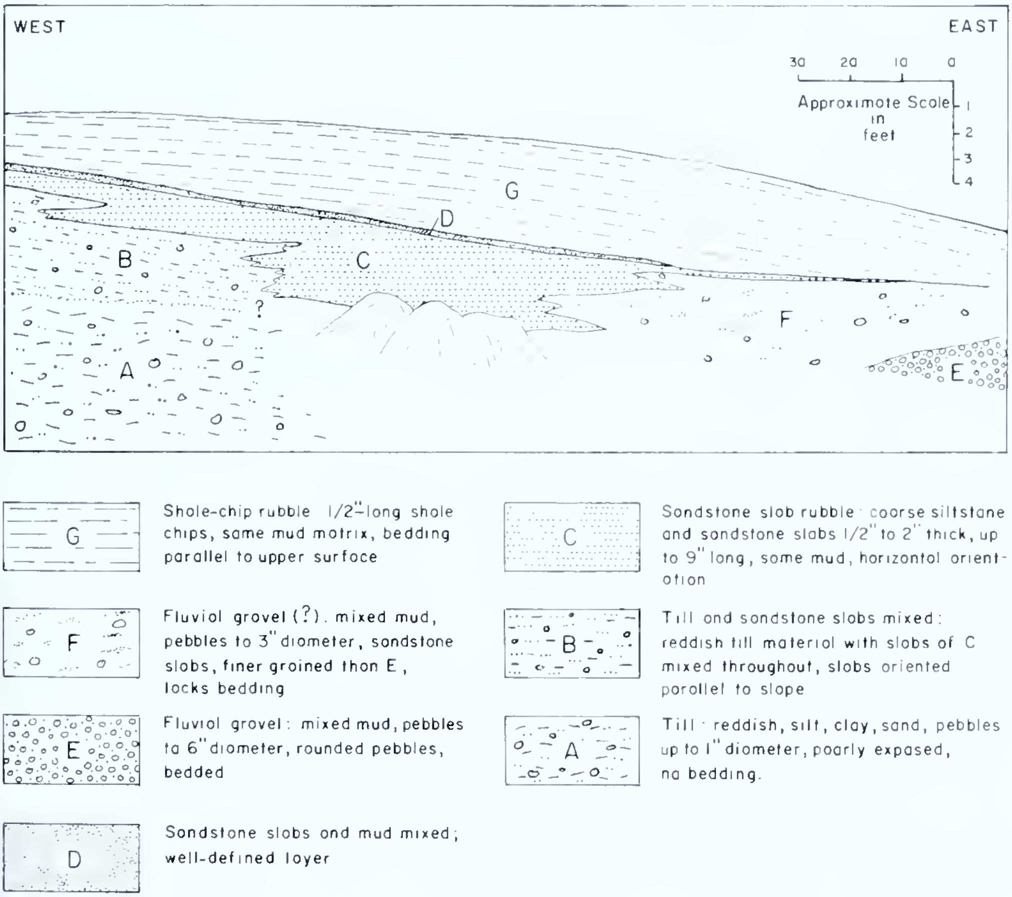

WEST
EAST
30 20 10 0
Approximate Scale in feet
1
2
3
4
G
D
B
C
?
F
A
E
G
Shale-chip rubble 1/2"-long shale chips, same mud matrix, bedding parallel to upper surface
C
Sandstone slab rubble: coarse siltstone and sandstone slabs 1/2" to 2" thick, up to 9" long, some mud, horizontal orientation
F
Fluvial gravel (?): mixed mud, pebbles to 3" diameter, sandstone slabs, finer grained than E, lacks bedding
B
Till and sandstone slabs mixed: reddish till material with slabs of C mixed throughout, slabs oriented parallel to slope
E
Fluvial gravel: mixed mud, pebbles to 6" diameter, rounded pebbles, bedded
A
Till: reddish, silt, clay, sand, pebbles up to 1" diameter, poorly exposed, no bedding.
D
Sandstone slabs and mud mixed; well-defined layer

Figure 119. Field sketch of shale-chip rubble, sandstone-slab rubble, till, and fluvial gravel deposit in an exposure behind a garage on the north side of Pa. Route 443 a few hundred yards west of the junction of Pa. Route 443 and U.S. Route 209 at Lehighton.

an outcrop upslope to the north just prior to being covered by the Illinoian(?) glacier. The scattered erratics of quartzite in the gravel may have been derived from pre-Illinoian(?) drift that may have been present on the hill.

### *Boulder Fields*

Three boulder fields have been mapped in the area: two southeast of Bowmanstown (Sevon, 1967a) and one at the crest of Blue Mountain at Little Gap.

The Bowmanstown boulder field is located immediately southeast of Bowmanstown (Plate 2). "The boulder field floors an open northeast-southwest trending valley and has the following dimensions: approximately three-fourths of a mile long, 750 feet wide at the western end and 600 feet wide at the eastern end. . . . The western end of the boulder field has been modified by housing development and transportation systems and the eastern end is obscured by soil and vegetation. The field surface has a gradient of 4½° to 5° southwest with no perennial streams or integrated drainage and is covered with scrub oak, pine, other small trees and greenbrier except where the boulder-enclosing matrix has been removed." (Sevon, 1967a, p. 90). The matrix-free area (Figure 120) occurs as fingers extending northeastward from the southwestern end of the

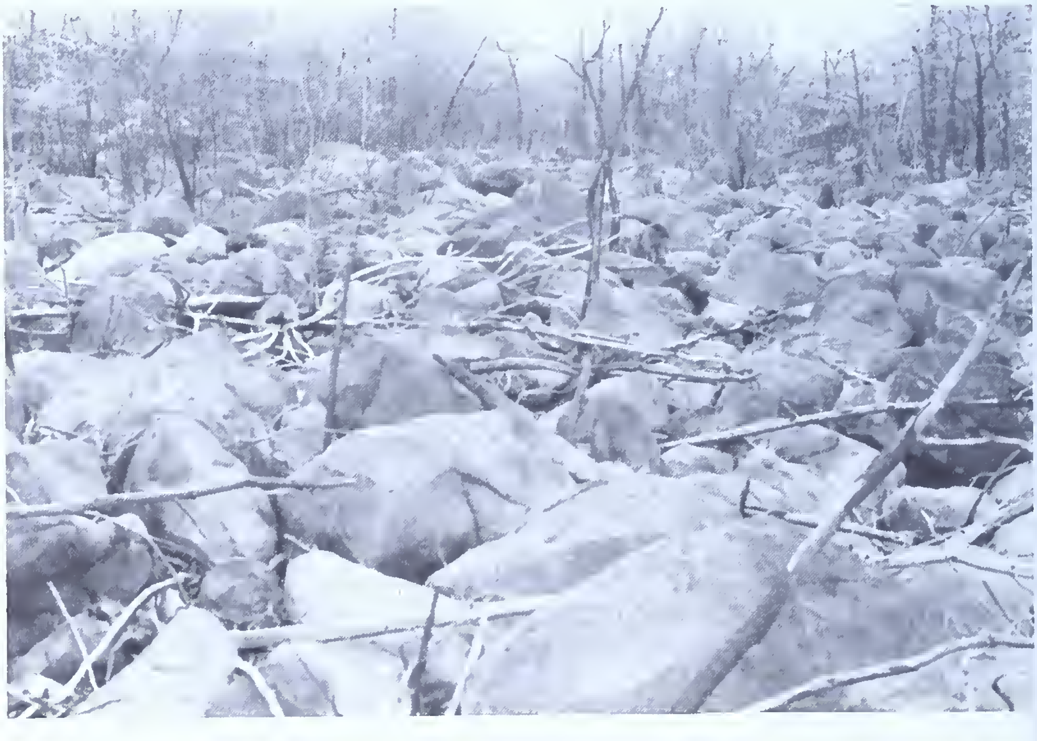


Figure 120. Surface of the Bowmanstown boulder field in a matrix-free area. Boulder field is at southeast edge of Bowmanstown.

boulder field. The valley is bounded on the north by a sharp narrow rock ridge rising 60 to 80 feet above the valley floor and on the south by a broad rounded rock ridge rising 100 to 120 feet above the valley floor.

The following description of the boulder field is taken from Sevon (1967a, p. 92-93):

> The Bowmanstown boulder field comprises sandstone boulders averaging 1 to 2 feet in diameter in an unsorted interstitial matrix of silt, sand, and fine angular pebbles. . . . In the western end of the field where the matrix has been removed, the boulders are almost exclusively Palmerton sandstone and vary in size from about 6 inches in diameter to an observed maximum of 20 to 10 by 8 feet. The boulders are subrounded in shape, have rough-textured, weathered surfaces with numerous protruding small quartz pebbles and are stable with several point contacts per boulder. . . . [Schoharie-Esopus] siltstone occurs mainly as small angular pebbles in the matrix and Ridgeley sandstone boulders are rare. The overall appearance of the matrix-free area is one of flatness despite the surface unevenness created by irregular hollows and projecting boulders. There are few irregularities disrupting the flatness of the area having matrix present. No observations have been made of those boulders still enclosed in matrix. The total thickness of the deposit is not known, although the matrix has been removed to a depth of 5 feet in some places.
>
> The unbent attitude of trees and the undisturbed positions of pieces of spall rock on boulders indicate that there is no mass movement within the field at the present time.
>
> The freshly weathered appearance of the matrix at the margins of the matrix-enclosed area suggests that headward erosion is an active process in the field. Surface concentrations of angular pebbles near these margins may indicate sheet-wash removal of sand and silt as the initial process of the erosion.
>
> The boulder field appears more continuous into the marginal talus deposits to the north than into those to the south, but matrix and vegetation obscure the relationship. The northern ridge has a small talus accumulation along its southern base which grades evenly into the boulder field within a few tens of feet. The talus deposits along the northern base of the south ridge appear to be small in volume and have well-defined slope changes at their boundaries with the boulder field and scree slopes. Scree is well developed on the north side of the southern ridge and contrasts with the boulder field. On the southwestern part of the ridge the scree comprises hard, smooth-surfaced angular blocks of Palmerton sandstone with little or no enclosing matrix. The blocks are partially unstable and the jumbled nature of the mass suggests that some movement has occurred, but there is no indication of present movement. On some eastern and central parts of the ridge, hard, smooth-surfaced, angular, pebble-sized fragments of Bowmanstown siltstone form a scree veneer. The scree and talus deposits are not actively forming at present, but the unweathered appearance of the scree suggests that it is younger in origin than the boulder field.

A smaller boulder field east of the Bowmanstown boulder field is apparently similar in character but has very little matrix removed by erosion and has a steep front presumably typical of rock glaciers.

Areas covered with jumbled boulders of various sizes are common on the top and the slopes of Blue Mountain. One is shown at Little Gap on Plate 2 and is known locally as "Devil's Potato Patch" (Ver Steeg, 1930). A photograph is shown in Miller and others (1939, p. 121, pl. 4B). The boulder field lies at an altitude of about 1,090 feet, just south of the crest of Little Gap. The open field is about 400 feet long and 100 feet wide, but boulders underlie tree-covered terrain in all directions. It lies on the outcrop belt of the Minsi Member of the Shawangunk Formation, but the boulders were derived from the Minsi and Weiders Members that underlie the slopes to the east and west. No bedrock is exposed in the field. The slopes are also covered with coarse rubble and no outcrops were found. The slope of the field is about 2° SE. The boulders, as much as 8 feet long, are jumbled and loosely packed. Many are in semistable positions and stand on edge. The surface of the field is flat in overall view, but there is some unevenness, depressions being about 4 feet deep.

Whether there is any movement in the field at present would have to be determined by careful measurements over a period of years. Running water may be heard below the blocks (Ver Steeg, 1930), so fine particles are probably being washed out and the boulders are being broken down by weathering. Similar boulder fields in Pennsylvania and elsewhere are believed to have developed during intensified mechanical disintegration and mass movement under periglacial conditions; at present the fields are in a stage of decay (for example, see Smith, 1953).

### *Colluvium*

Colluvium is a term applied to unconsolidated materials which are shed from disintegrating bedrock hills or cliffs and which moved downslope under the influence of gravity. Movement may be aided by saturation with water (solifluction) and also by alternate periods of freeze and thaw (frost heaving). A series of deposits may form on very steep slopes, such as along the south face of Blue Mountain. At the top, huge blocks of rock, many more than 10 feet long, fall from the cliff face and often come to rest in unstable positions. These blocks are somewhat diminished in size as mass movement proceeds downslope, and the talus deposit formed will reach equilibrium at the angle of repose, generally 25° to 35°. Farther downslope, as the blocks are reduced in size, the percentage of sand, silt, and clay increases. Soil may cover large areas, and vegetation is more prolific. At this point, it is difficult to distinguish the colluvium from Illinoian(?) till without good exposures. The downslope decrease in size of material in colluvium along the lower south slope of Blue Mountain is shown in Figure 121.

In the higher reaches of the talus pile, the boulders generally lie in jumbled heaps, but in many places, masses of these boulders, many of which are imbricate, extend as lobes downslope for distances more than 100 feet and extend out over much finer materials below (see Figure 121). These are either rock glaciers that flowed downslope or are solifluction or creep phenomena similar to those described by Potter and Moss (1968).

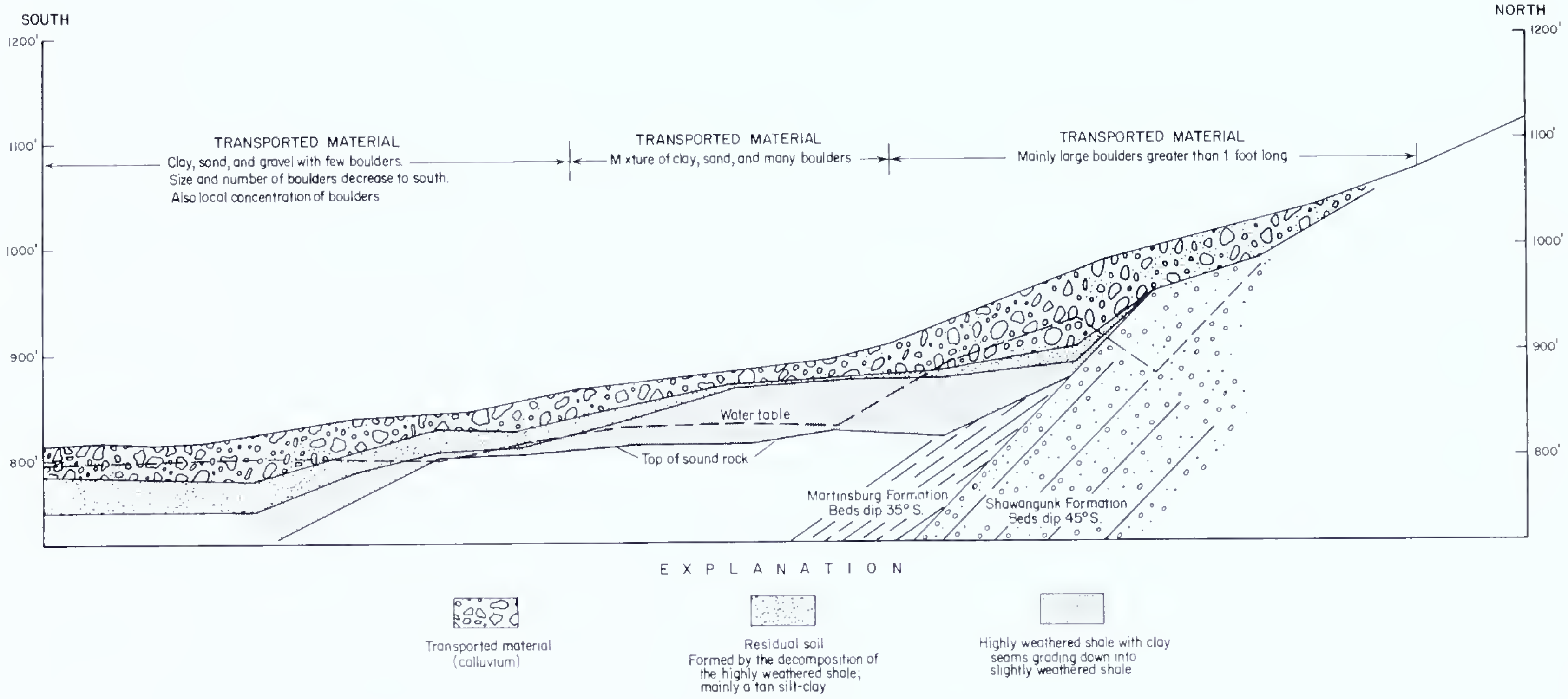

SOUTH
NORTH
1200'
1100'
1000'
900'
800'
TRANSPORTED MATERIAL
Clay, sand, and gravel with few boulders.
Size and number of boulders decrease to south.
Also local concentration of boulders
TRANSPORTED MATERIAL
Mixture of clay, sand, and many boulders
TRANSPORTED MATERIAL
Mainly large boulders greater than 1 foot long
Water table
Top of sound rock
Martinsburg Formation
Beds dip 35° S.
Shawangunk Formation
Beds dip 45° S.
EXPLANATION
Transported material (colluvium)
Residual soil
Formed by the decomposition of the highly weathered shale; mainly a tan silt-clay
Highly weathered shale with clay seams grading down into slightly weathered shale

Figure 121. Cross section through south slope of Blue Mountain along the Northeast Extension of the Pennsylvania Turnpike in the Lehighton quadrangle showing colluvium, soil, and weathered rock on the Martinsburg and Shawangunk Formations. The contact between the Martinsburg and Shawangunk is an angular unconformity of 10°. Modified from Pennsylvania Turnpike Commission reference drawing 606-20-G-2, 1954 (unpub.). Vertical scale same as horizontal.

Transverse and longitudinal ridges and furrows, commonly with a relief as great as 10 feet, attest to variation in the rate of flow. On the denuded steep slope in the Lizard Creek Member of the Shawangunk Formation south of Aquashicola Creek and south of the sewage disposal plant in Palmerton, there are several "debris chutes." These are at least 200 feet long and contain rubble from the surrounding bedrock. The rubble is composed of shale and sandstone fragments ranging from small chips to boulders nearly 5 feet long. Levees lie along the longitudinal margins of the chutes. From crest to crest of the levees, the chutes are about 10 feet wide and 1.5 feet deep. These features are active at the present time, as indicated by abundant slide-rock traveling down the chutes onto the railroad below.

Vegetation is advancing over many presently inactive talus slopes, especially on their lower margins. Higher up, on steeper slopes, however, talus is still accumulating, as indicated by trees that have been knocked over by boulders, by lichens on the undersides of some boulders, and by the very unstable position of many boulders. Commonly, during the spring thaw, rocks can be heard falling along the south slope of the mountain.

Only the thick accumulation of coarse colluvium along the south slope of Blue Mountain was mapped (Plate 2). The thickness of this deposit is probably greater than 50-70 feet in many places (see Figure 121). Where it overlies the Martinsburg Formation, a thick interval of weathered slate and soil underlies it. A veneer of colluvium is also present over most areas of the quadrangle, and the colluvial cover may be thick in places on the north slope of Blue Mountain. It is as much as 50 feet thick at the north portal of the Lehigh Tunnel on the Northeast Extension of the Pennsylvania Turnpike. Mapping the colluvium here is difficult because the colluvial rubble is composed principally of fragments from the underlying Bloomsburg Red Beds, and the depth to bedrock cannot be easily judged. Along the road north from Lehigh Furnace Gap where the cuts are 5 feet deep or more, there is no bedrock exposed and the colluvium may be very thick, especially at lower altitudes. It is probable, therefore, that where bedrock is not exposed on Blue Mountain, as indicated on Plate 1, a thin to thick veneer of colluvium blankets the surface.

Colluvium is generally thin in the outcrop belt of the Martinsburg Formation, but weathered slate that is readily moved with power equipment may be more than 10 feet thick (Figure 122) and in places more than 50 feet thick (Figure 121). The slow downward creep of the colluvium is indicated by downslope bending of the underlying bedrock (Figure 122).

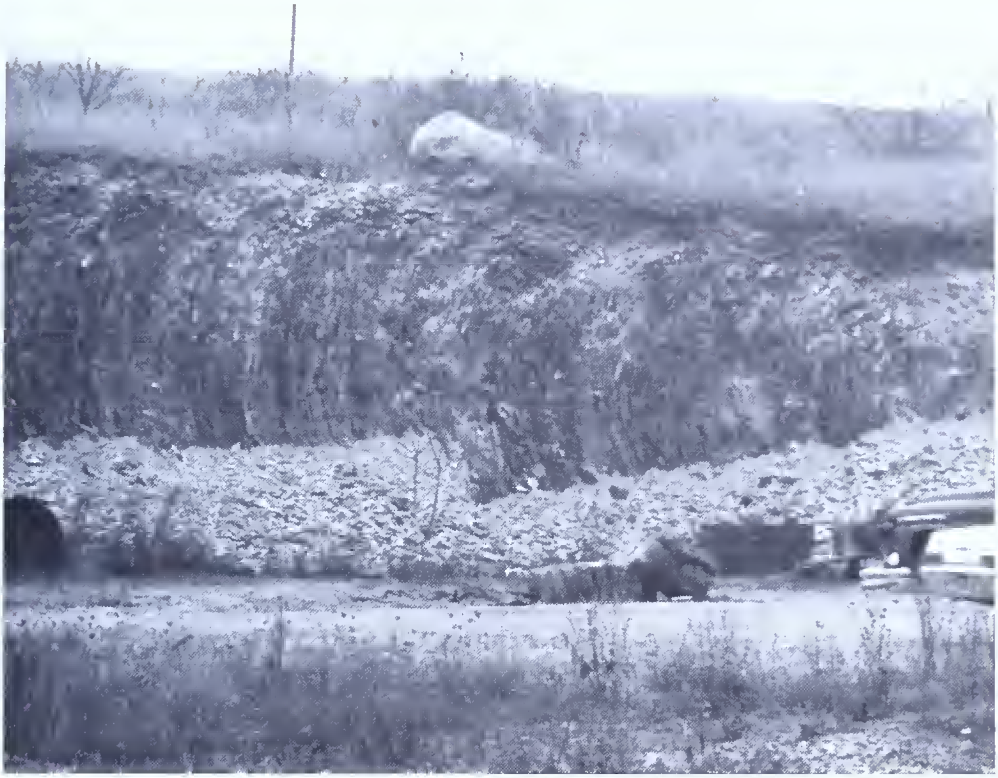


Figure 122. Weathered Martinsburg slate, about 15 feet thick, in a borrow pit along the east side of Pa. Route 145, 1 mile north of Walnutport. Bedding and cleavage are about vertical in the undisturbed rock and have been bent downslope by the slow creep of colluvium. Colluvium at the top of the exposure is 2–3 feet thick.

As mentioned previously, much colluvium along the south slope of Stony and Chestnut Ridges has been mapped as Illinoian(?) outwash, which interfingers with the colluvium. Two samples of this colluvium (samples 8 and 9) are very poorly sorted with a clay-silt matrix. The petrographic and mineralogic characteristics of these are given in Tables 9-12 and Figures 132 and 133.

Extensive deposits of colluvium occur on both sides of Stony Ridge east of Ashfield. These deposits comprise sandstone boulders enclosed by a moderate-reddish-brown (10R4/6) matrix of pebbles, sand, silt and clay. The colluvium results from mass movement, by gravity, of materials weathered from the rocks forming Stony Ridge. The texture of these deposits is variable. Near Walkton the colluvium consists of about 50 percent pebbles and boulders set in a matrix; most of the pebbles are less than 3 inches in diameter, a few pebbles are 3 to 9 inches in diameter, and rare boulders are up to 2½ feet in diameter. Colluvium boulders up to 12 feet long are exposed in Fireline Creek northeast of Bowmanstown.

The surfaces of these deposits are often littered with numerous boulders (Figure 123). In many places on the north side of Stony Ridge there is a sharp contrast between the surfaces of adjacent colluvium and shale deposits.

Colluvial deposits on the south slope of Stony Ridge have been mapped, but other colluvial materials north of Stony Ridge have not been mapped. The Stony Ridge colluvium differs in composition from the underlying bedrock lithologies, allowing easy mapping, whereas colluvial material developed elsewhere is often identical to the underlying bedrock and is thus difficult or impossible to map without subsurface information. The steep north-facing slopes bounding the south side of Pohopoco and Mahoning Creek valleys have extensive deposits of debris from the Trimmers Rock Formation and the Towamensing Member of the Catskill Formation. However, these deposits are not readily discernible from normal weathering products of the Trimmers Rock Formation and are generally observed only in artificial cuts such as that shown in Figure 124. The deposit shown in Figure 124 is over 30 feet thick and consists of poorly bedded zones of siltstone slabs 1 to 2 feet long and 2 to 6 inches thick in a somewhat finer matrix (Figure 125). Some zones are chaotic while others are imbricated and distinctly sorted. Such

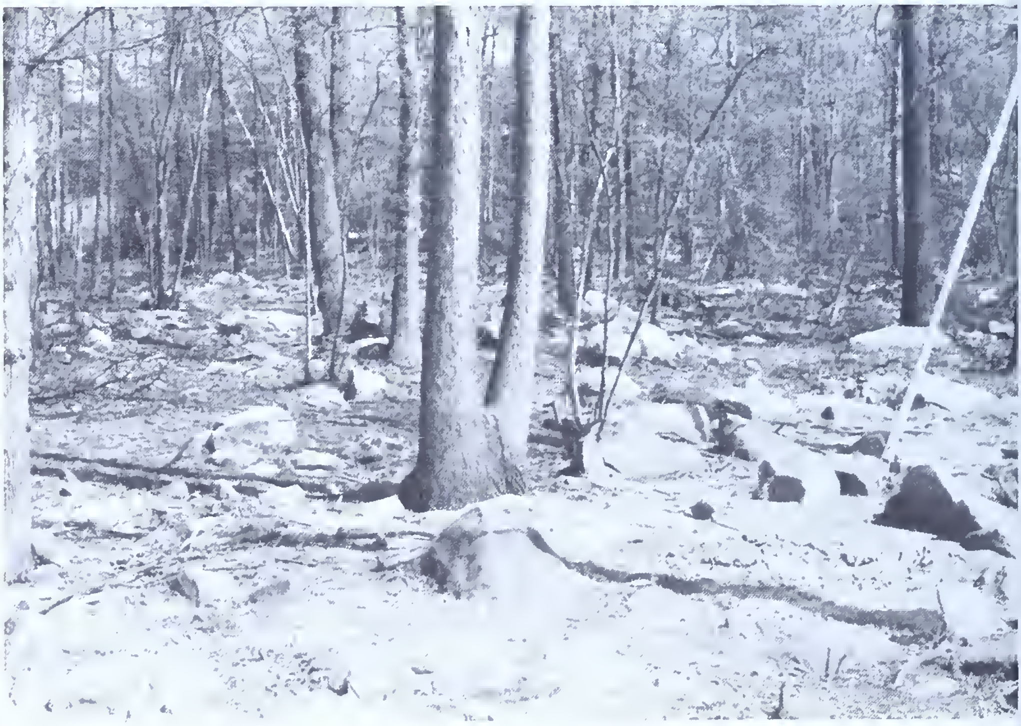


Figure 123. Surface of colluvium deposit just south of Christian Corner.

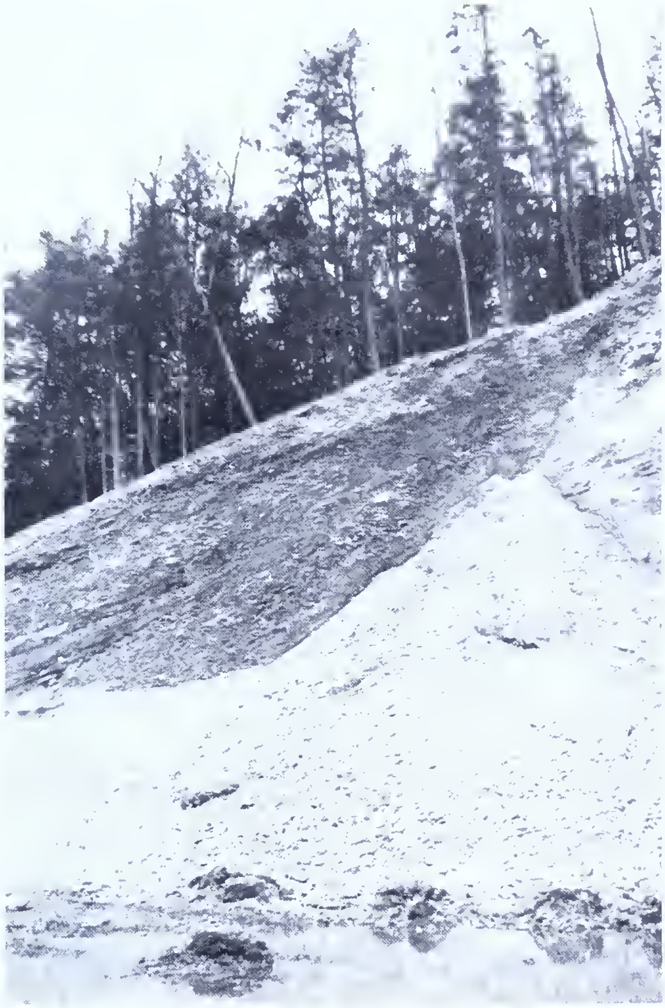


Figure 124. Talus of colluvium developed on a steep slope of Trimmers Rock siltstone along south bank of Pohopoco Creek at the left abutment of the Beltzville Dam.

deposits are probably the result of talus development along the side of a valley oversteepened by glaciation.

An initial stage of colluvial development is illustrated in Figure 126. This exposure shows disintegrated Mahantango shale disturbed near the surface by creep. The extent to which the mapped area is affected by movement of this nature is not known.

## Holocene

### *Alluvium*

Deposits of alluvium are extensive and variable. Some alluvial material was deposited in nearly all drainage channels, but there is considerable variation in the nature and extent of the deposits. The most extensive

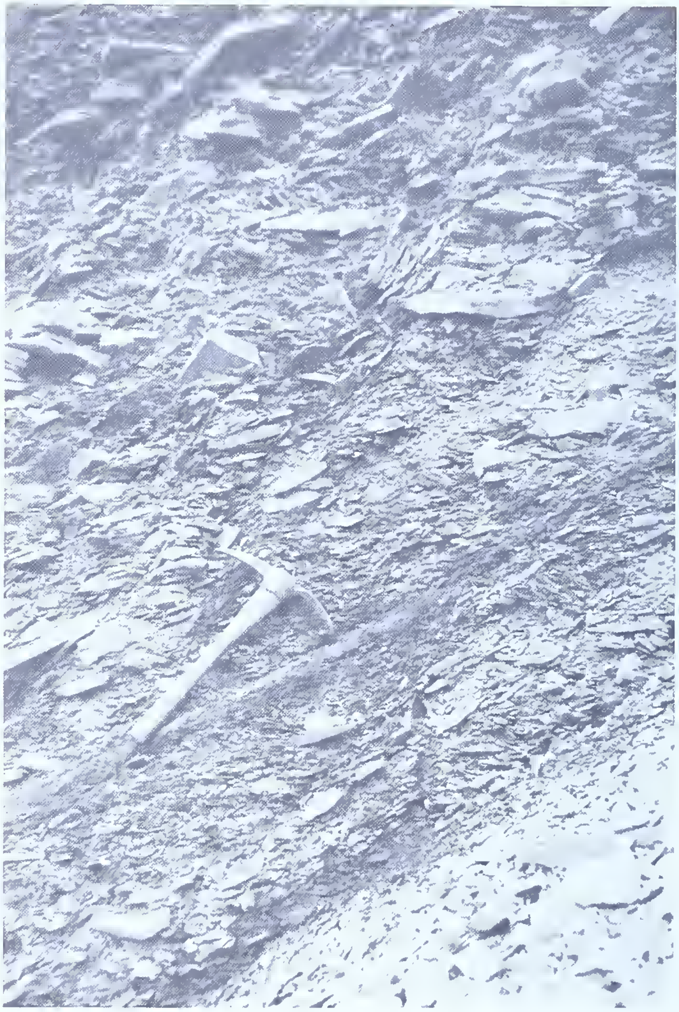


Figure 125. Bedding detail of talus deposit shown in Figure 124.

alluvium is in the Lehigh River valley and the valleys of Lizard, Aquashicola, and Mahoning Creeks. Some alluvium is present in Pohopoco Creek valley, but the thickness of this alluvium is considerably less than the thicknesses of alluvium deposits in the other creeks of similar size.

The alluvium exposed above water level along the Lehigh River is generally similar throughout the area north of the junction of Aquashicola Creek with the Lehigh River. Measured section 22 is probably typical of these deposits.

In a similar section near Kittatinny (8,200 feet west of longitude 75° 37′30″ and 14, 950 feet north of latitude 40°45′), a lense of light-gray sandy clay occurs 6 feet below the floodplain surface. A sample of wood and charcoal fragments was collected from this bed and the charcoal was

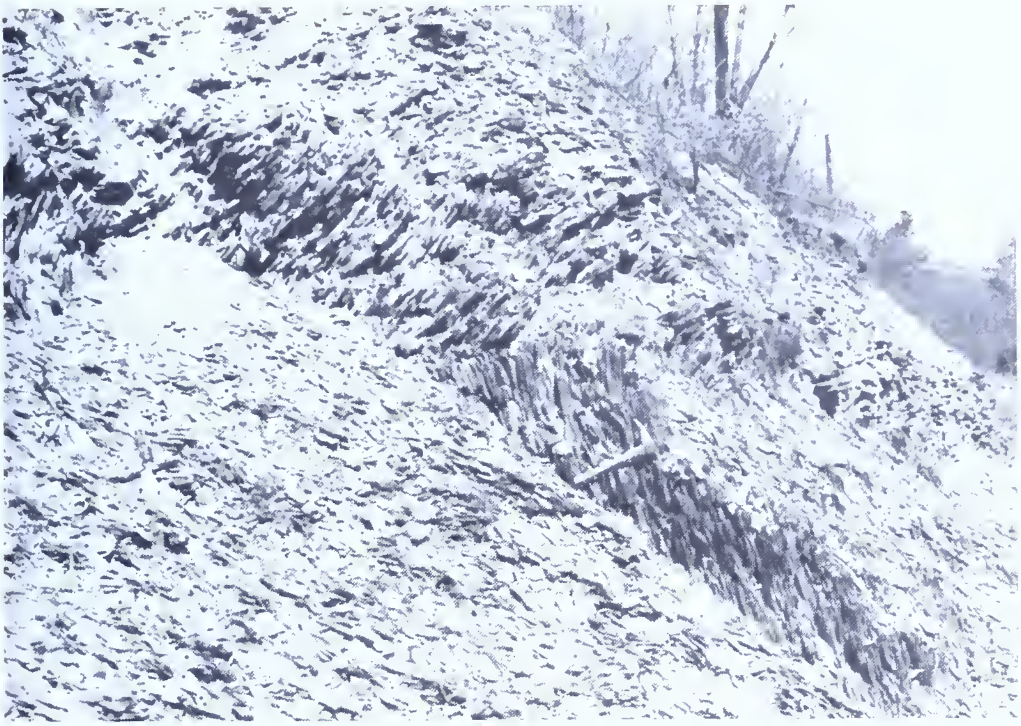


Figure 126. Creep disturbance of Mahantango shale showing prominent cleavage in old borrow pit at north edge of Aquashicola.

dated at 1,890 ± 100 years B.P. (dating by Isotopes Inc.). The overlying sand has coal dust intermixed in the uppermost 2 feet.

Alluvial sequences similar to that described above are numerous along the Lehigh River, but in most places the sand has been removed by erosion and a broad boulder pavement with tongues of sand and surface channels remains. Boulder pavements are well developed at the river bend southwest of Palmerton, west of Bowmanstown, and east of Lehighton (Figure 127).

The character of the alluvium in Lizard Creek is virtually unknown because of lack of exposure. It appears to be a poorly sorted mixture of clay, silt, sand, and boulders, and is similar to the colluvium formed adjacent to Stony Ridge. The boulders are sandstones apparently derived from both Stony Ridge and Blue Mountain. The alluvium in both Mahoning Creek and Pohopoco Creek is also a poorly sorted mixture of clay, silt, sand, and boulders, but the boulders are smaller in size than those in Lizard Creek and also are dominantly Catskill sandstones and conglomerates derived from glacial deposits.

The thickness of alluvium is poorly known, but three cross sections compiled from data on file with the Pennsylvania Turnpike Commission,

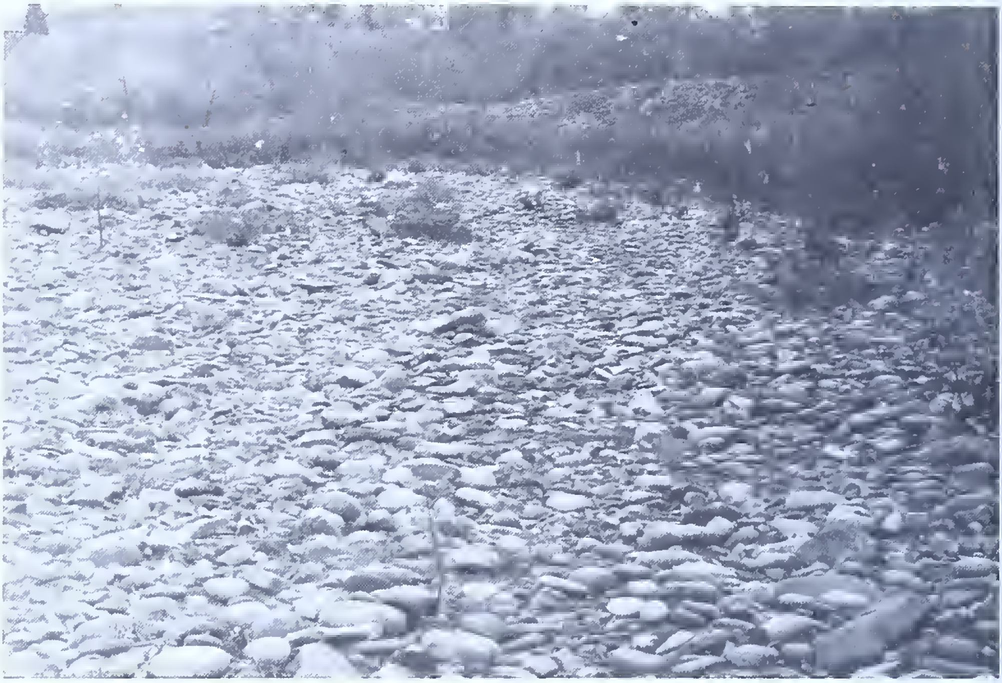


Figure 127. Surface of Lehigh River alluvial plain at Lehighton.

Harrisburg (Figures 128-130), indicate the character and thickness of the alluvium where the Northeast Extension of the Pennsylvania Turnpike crosses Lizard Creek, the Lehigh River and Pohopoco Creek. The thickness of material below water level is somewhat surprising as elsewhere in the area Pohopoco Creek is flowing on bedrock.

Alluvium has been mapped in most small creeks, but only a few generalities can be made about these deposits. In general, those alluvial deposits in Silkmill Run (at Jim Thorpe) and streams draining the Weir Mountain syncline and flowing into Buckwha, Aquashicola, or Lizard Creek are usually thin and contain locally derived material. The material is usually clay, silt, and sand, depending upon the dominant lithology in the drainage basin, but some plate-shaped pebbles are present. Bedding is common and there is some imbrication of pebbles. These deposits are probably seldom more than 5 feet thick.

Alluvial deposits in those streams north of the Weir Mountain syncline and flowing into Mahoning or Pohopoco Creek and including Long and Beaverdam Runs are dominated by Catskill sandstone and conglomerate boulders which have been eroded from Illinoian(?) glacial deposits. The remainder of the alluvium is a mixture of clay, silt, sand, and pebbles. Clay and silt are generally abundant, a reflection of the eroded glacial material. The sorting of these alluvial deposits is generally poor, probably a reflection of breadth of initially eroded materials. The boulders

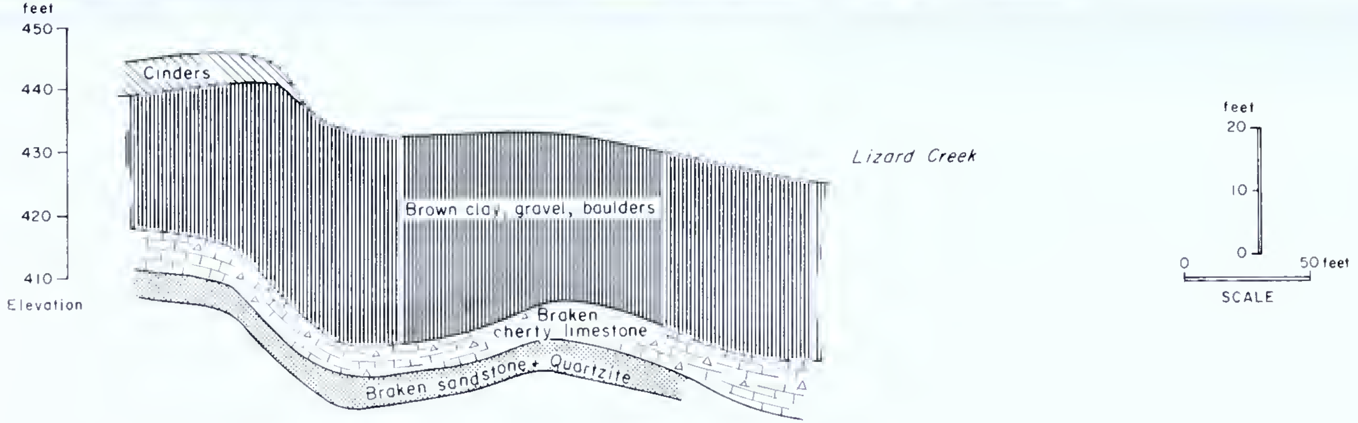


Figure 128. Cross section of surficial material in south side of Lizard Creek valley near Lizard Creek. Line of section is center line of Northeast Extension of the Pennsylvania Turnpike. Section starts at survey station 81 + 81.0′ and extends to 84 + 33.5′. Data from files of Pennsylvania Turnpike Commission, Harrisburg.

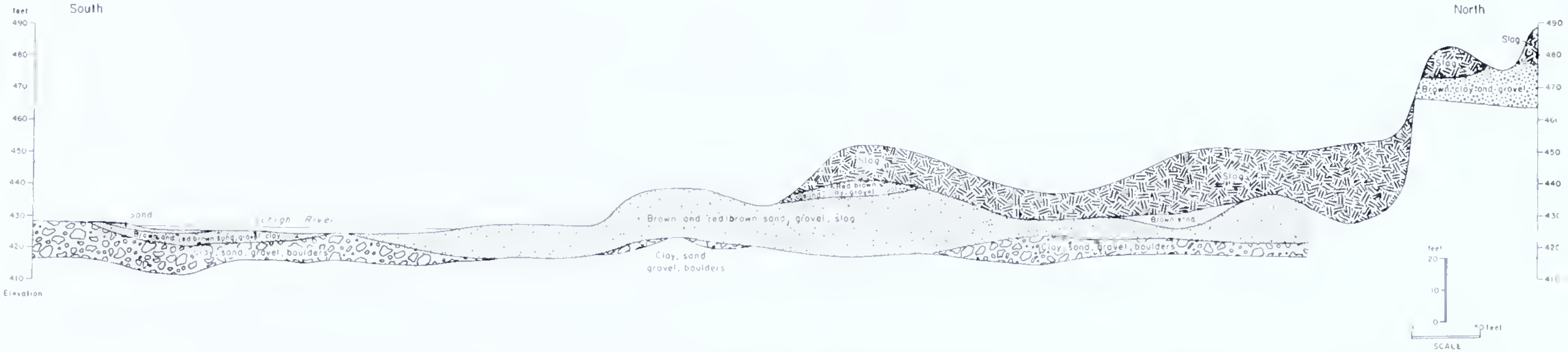


Figure 129. Cross section of surficial material in Lehigh River valley near Parryville. Line of section is center line of the Northeast Extension of the Pennsylvania Turnpike. Section starts at survey station 170 + 71.8′ and extends to 182 + 37.6′. Data from files of Pennsylvania Turnpike Commission, Harrisburg.

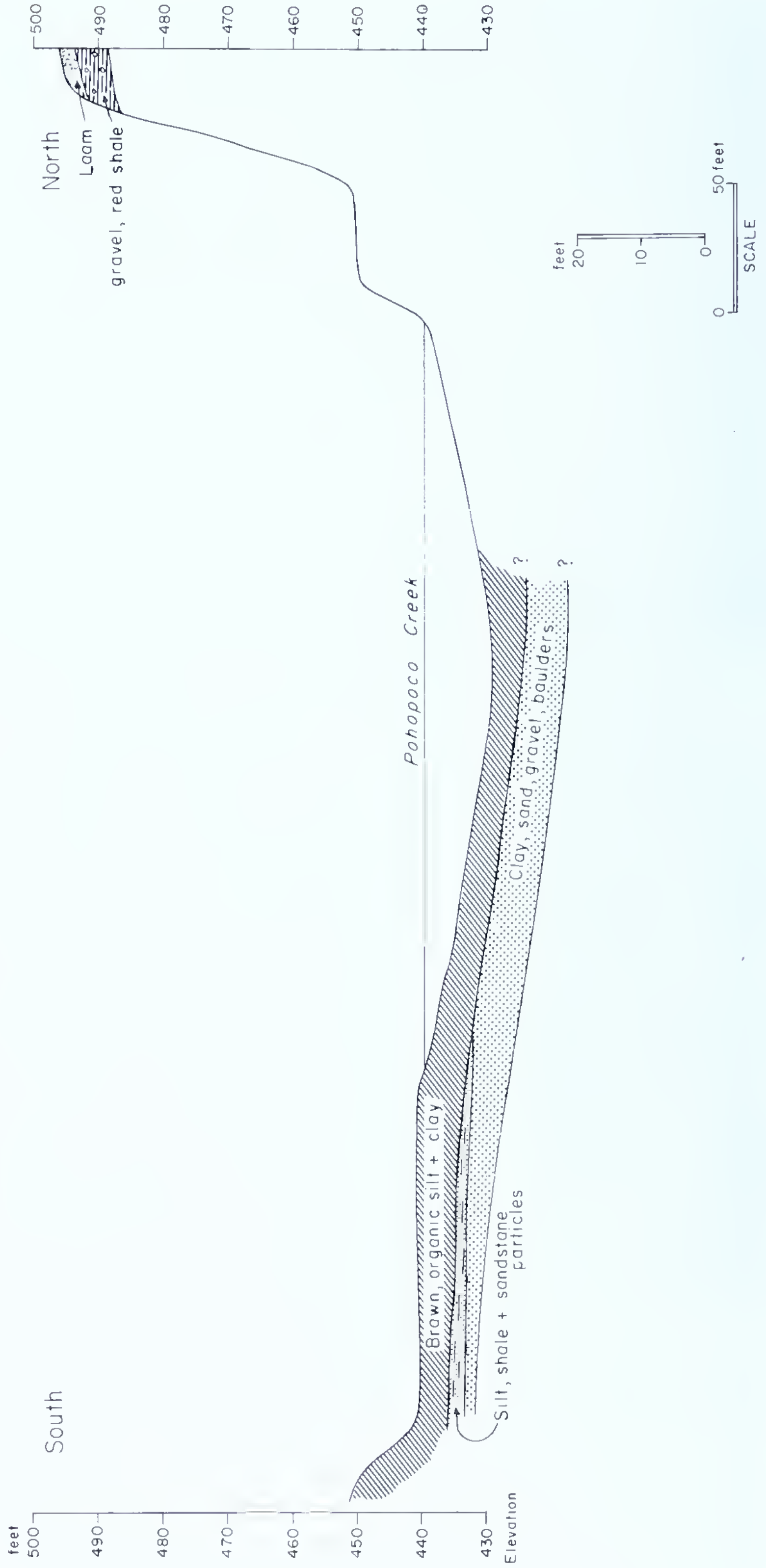


Figure 130. Cross section of surficial material in Pohopoco Creek valley at Harrity. Line of section is center line of the Northeast Extension of the Pennsylvania Turnpike. Section starts at survey station 192 + 10′ and extends to 197 + 10′. Data from files of Pennsylvania Turnpike Commission, Harrisburg.

are sometimes buried by the alluvium and sometimes rest on the alluvial surface. These boulders are probably not often in motion. The thickness of these alluvial deposits most likely does not often exceed 5 feet.

Along Aquashicola Creek, the alluvium is probably as much as 8 feet thick. At sample locality 2, it consists of at least 6 feet of medium to coarse brown (5YR3/4) sand in the basal 1 foot, grading up into very fine to medium moderate-brown (5YR3/4) sand. Analysis of a channel sample shows that the deposit is well-sorted (So = 2.4, Table 10), slightly pebbly muddy fine sand (Table 9, Figure 133). In places on the Wisconsinan outwash terrace near this locality there is one foot or less of alluvial sand that is probably reworked fines from the outwash, leaving the boulders in the outwash as a lag deposit. One-half mile east of Walkton, at least 4 feet of moderate-yellowish-brown (10YR5/4) silty sand was exposed in a trench along the pipeline.

The alluvium along Lehigh River south of its junction with Aquashicola Creek is generally similar to the alluvium along Aquashicola Creek, but it may be as much as 20 feet thick in places. At sample locality 1, the alluvium is about 10 feet thick and consists of moderate-brown (5YR4/4) slightly granular muddy fine sand. Gravel is fine and not abundant (Figure 132). It abruptly overlies more than 5 feet of Wisconsinan outwash gravel. At sample locality 3, the alluvium is horizontally stratified, is at least 9 feet thick, and contains approximately 50 percent coal in the upper 6 to 6.5 feet (measured section 23). The coal-bearing sand, which is common along the Lehigh River, probably correlates with the initiation of major coal mining about 1810. Therefore, about 6 feet of sand has been deposited during the past 160 years. In many places, however, this alluvium is thin along the Lehigh, and it occurs on lag boulders derived from the underlying Wisconsinan outwash or from adjacent pre-Wisconsinan terraces.

In general, the alluvium along the Lehigh River and its major tributaries is the best sorted of all surficial deposits in the Lehighton and Palmerton quadrangles (Table 11). Chlorite is found in the clay-sized minerals in the alluvium in Aquashicola Creek. Vermiculite and kaolinite are found in Aquashicola Creek and Lehigh River samples (Table 12). The chlorite is probably derived from Wisconsinan outwash in Aquashicola Creek; the vermiculite and kaolinite are derived from older surficial deposits and weathered bedrock (see Epstein and Hosterman, 1969, for X-ray analyses of weathered bedrock east of the Palmerton quadrangle).

### *Landslide Deposit*

A small landslide deposit occurs on the north slope of Bear Mountain about 1½ miles east of the Lehigh River at Jim Thorpe. The deposit is an elongate mound, about 2 to 5 feet high, which extends for several hundred feet upslope from the valley floor. Angular to subrounded sandstone boulders occur on the mound surface and also presumably form much of the deposit. The matrix is probably mixed sand, silt, and clay, but no exposures in the material have been seen. Some water seepage is associated with the deposit. The landslide resulted from rapid movement of loose bedrock and soil downslope from near the top of Bear Mountain. The movement probably resulted from saturation of the debris with water to the point that stability failure was followed by movement downslope by gravity.

### *Dumps*

Slate dumps are conspicuous features in the area of the slate quarries in the Martinsburg Formation south of Blue Mountain (Plates 2 and 4). Many dumps rise more than 60 feet above the surrounding land. They consist of waste blocks of slate. South of Palmerton on the north slope of Blue Mountain, there is a waste pile 2.25 miles long, about 1,000 feet wide, and 60-200 feet high (Figure 131). It is composed of clinker residue from smelting operations of the New Jersey Zinc Company at Palmerton. The uses of these waste materials are discussed in the section on mineral resources.

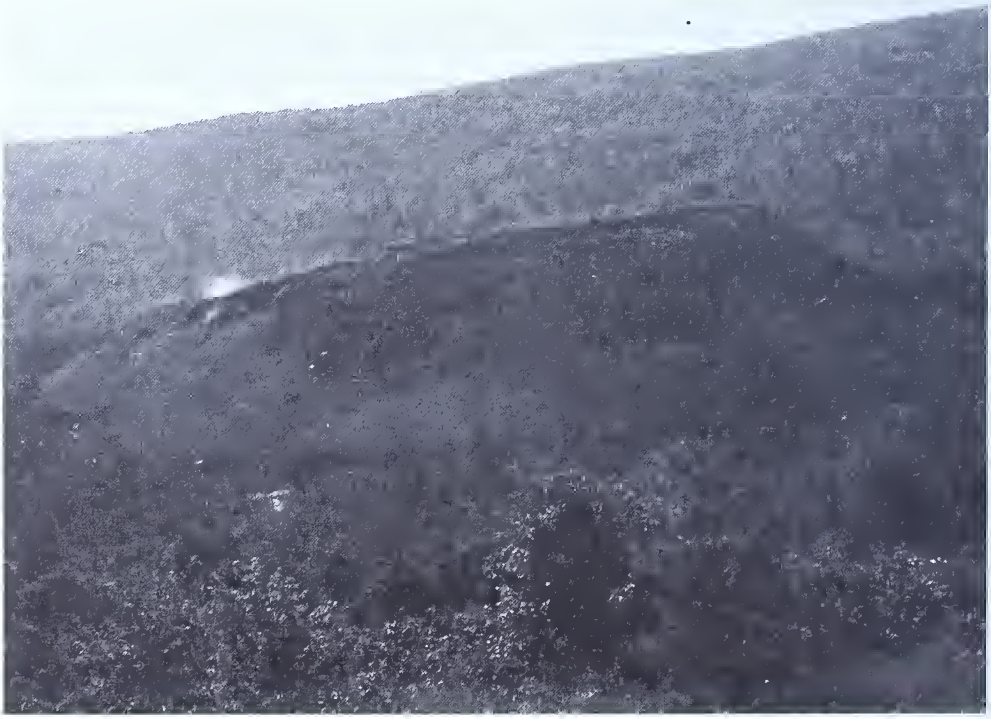


Figure 131. Waste pile of clinker residue of the New Jersey Zinc Company east of Palmerton. Some of the hot clinker is smoking to the left. The pile is about 200 feet high. Blue Mountain is in the background.

## Grain-Size Data

Fourteen samples, averaging about 2,620 grams each, were collected from various unconsolidated surficial deposits in the Palmerton quadrangle (see Plate 2). Gravel more than 8 mm in diameter was hand sieved through plywood screens with perforations drilled of the proper diameter. A split of about 300 grams was then made, silt and clay were separated by wet sieving through a 230-mesh screen, and the remainder was sieved in nested 8-inch screens for 30 minutes in a mechanical sieve shaker. Silt was separated from clay by settling in a deflocculated suspension for 2 hours and 3 minutes and siphoning off the upper 10 cm. This was repeated until the suspension was clear above 10 cm and all clay was removed. The silt was dried and weighed, and the percentage of clay and silt was computed. A histogram and cumulative curve were constructed (Figure 132), and various statistical parameters were calculated (Tables 9-11). One-phi intervals were used for sand and gravel up to 128 mm in diameter. Silt was averaged through four phi classes in construction of the histograms. The methods of computation and significance of the various parameters are described by Krumbein and Pettijohn (1938, p. 212-247).

No particles greater than 128 mm (about 5 inches) were collected. Because of this sampling bias in the coarser range, quartile measures were used. Quartile measures do not reflect the behavior of the extreme ranges (only the central part of the curve is considered in the statistical analysis) but moment measures are affected by every particle in the distribution, so the arithmetic mean and arithmetic standard deviation are included in the statistics.

If the fragments at the sample locality exceeded 5 inches, the maximum observed size is recorded in Table 9. The sample bias has undoubtedly affected many of the data. For example, the coefficient of sorting would be greater for those deposits from which coarser materials were not collected. Channel samples were collected for many deposits so that the approximate average texture could be determined. In some deposits, more than one bed was collected. For example, a 10-foot channel sample was collected of alluvium at sample locality 1 and the coefficient of sorting is higher (So = 2.6) than if a narrower interval were collected (So would probably be less than 2).

Because sorting and skewness vary geometrically, the logs of the two values were computed so that an arithmetic and direct comparison could be made.

Table 11 is a summary of the statistics of the surficial deposits in the Palmerton quadrangle. Alluvium along present streams is the best sorted deposit and, as to be expected, the finest grained deposit. The Illinoian(?)

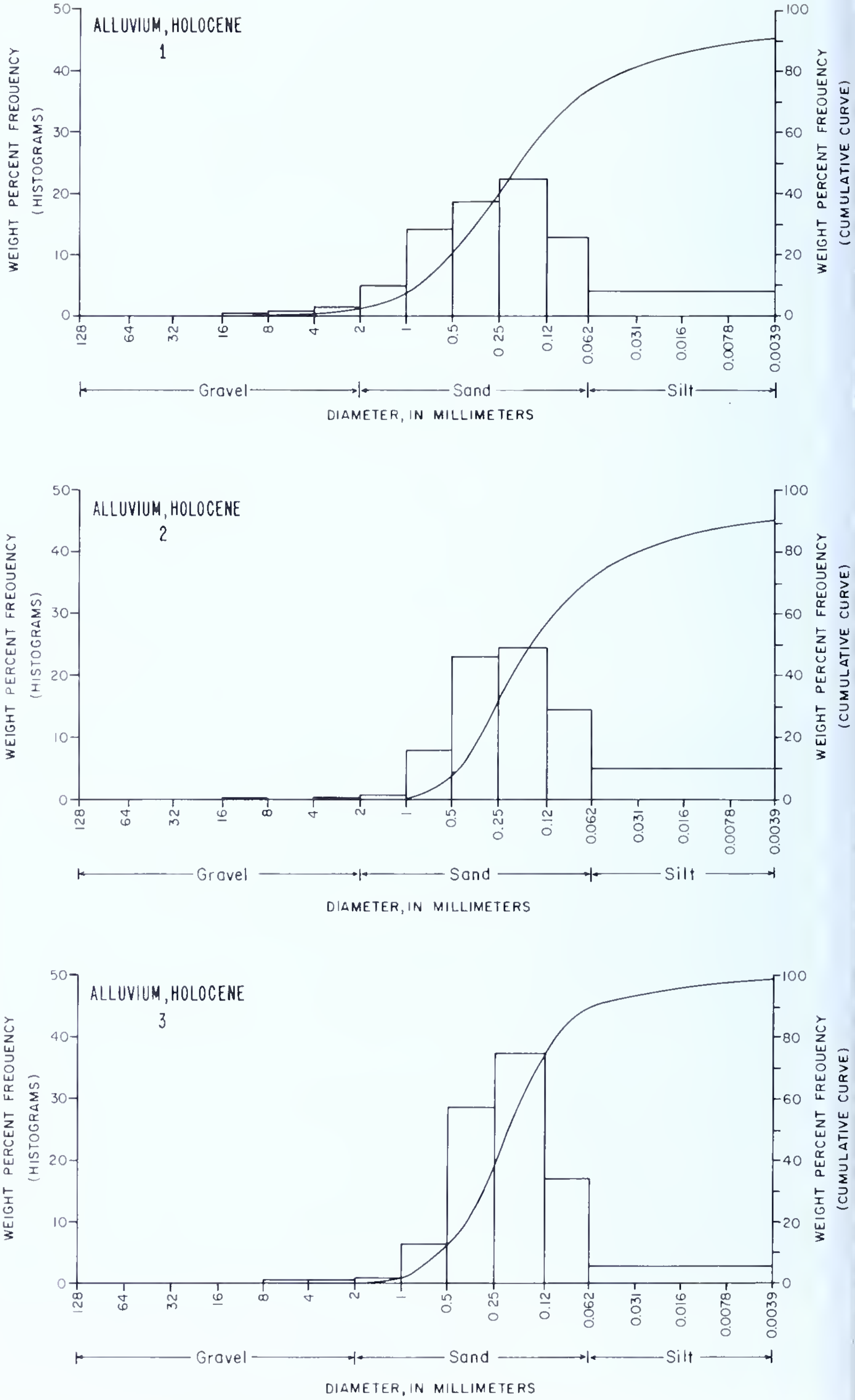


Figure 132. Histograms and cumulative curves for surficial deposits in the Palmerton quadrangle. Silt is averaged through four phi classes.

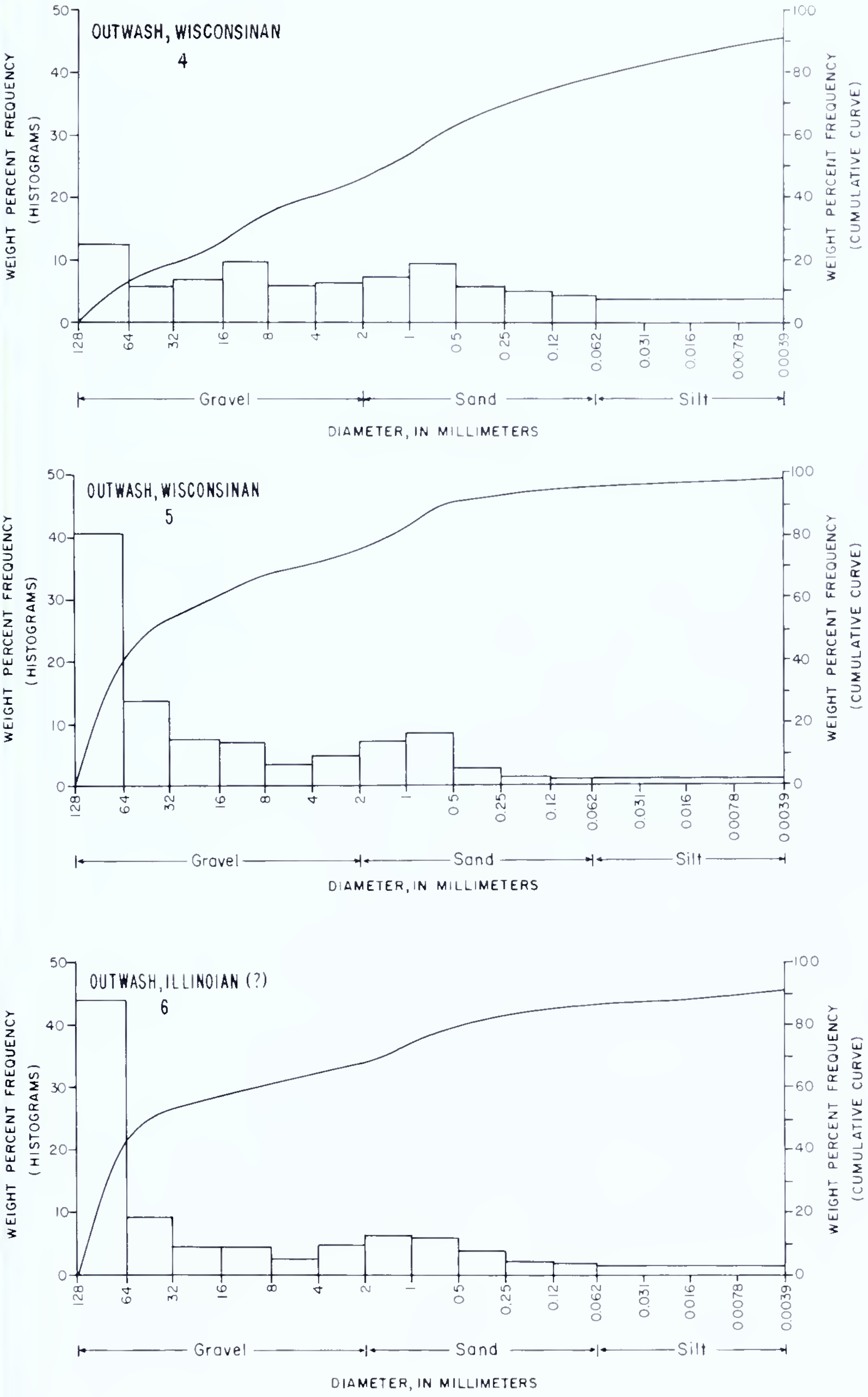


Figure 132. *(Continued)*

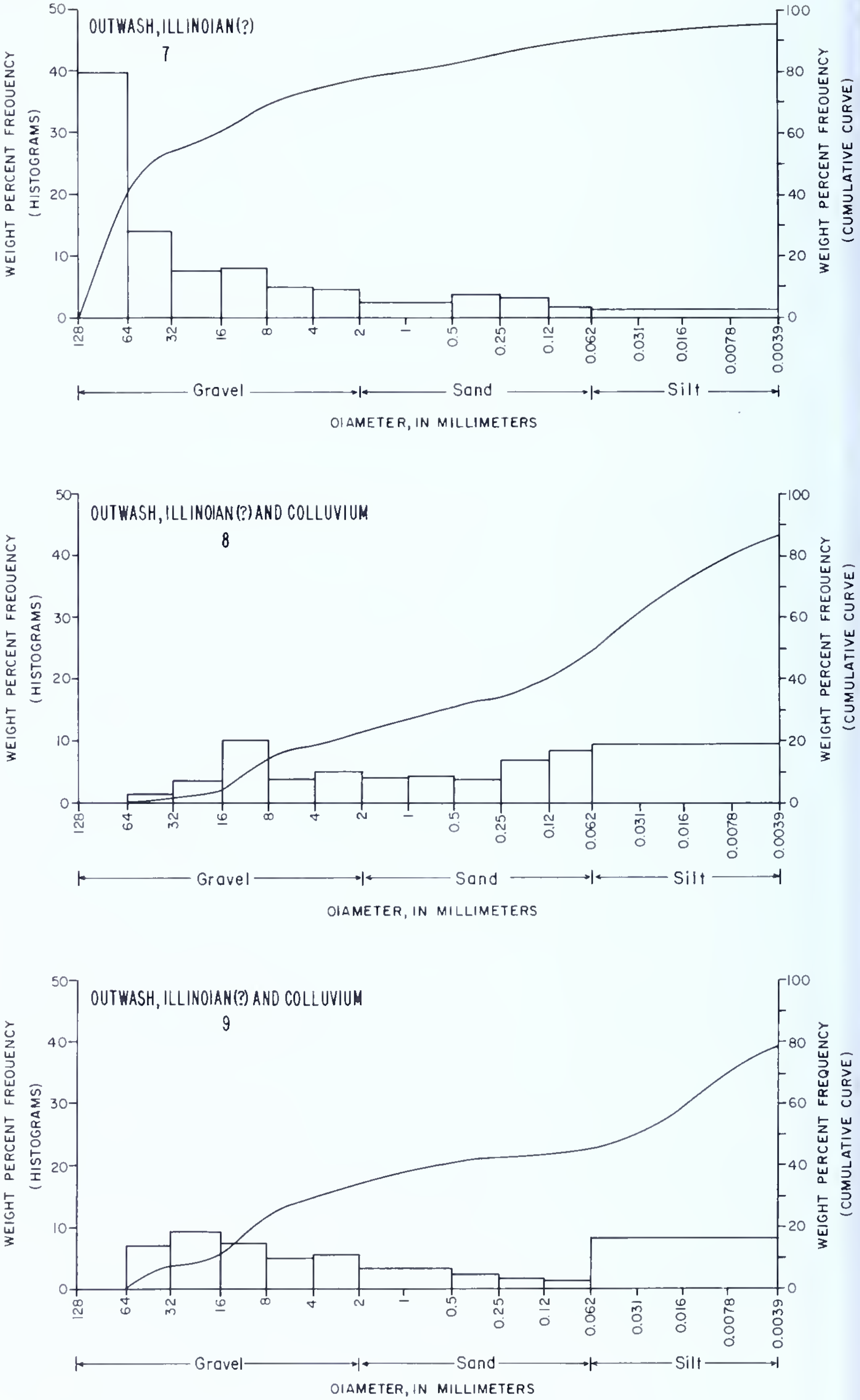
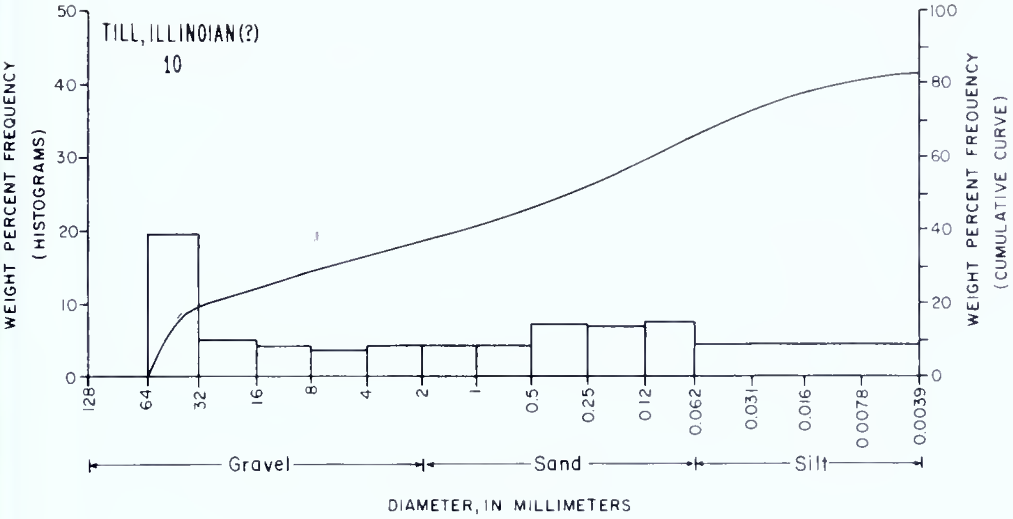
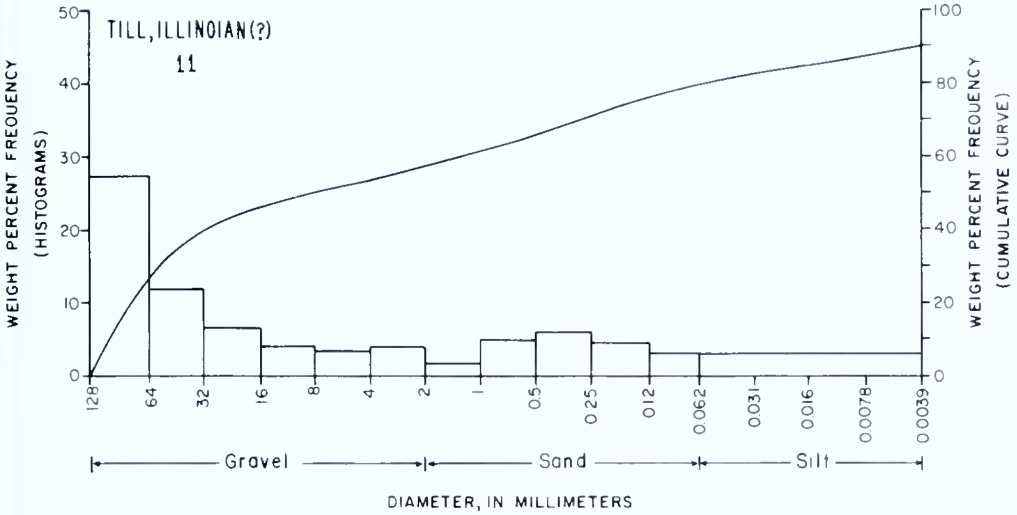


Figure 132. *(Continued)*





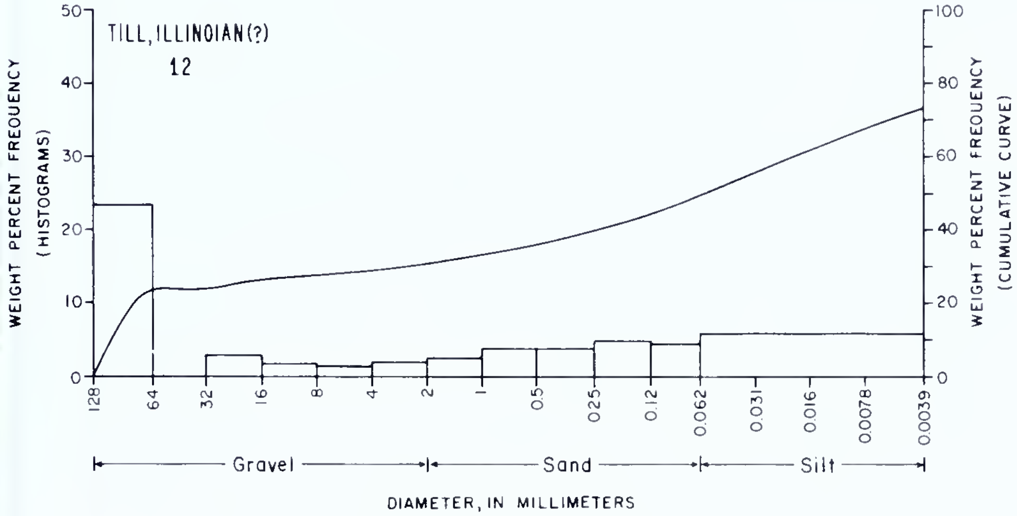


Figure 132. *(Continued)*

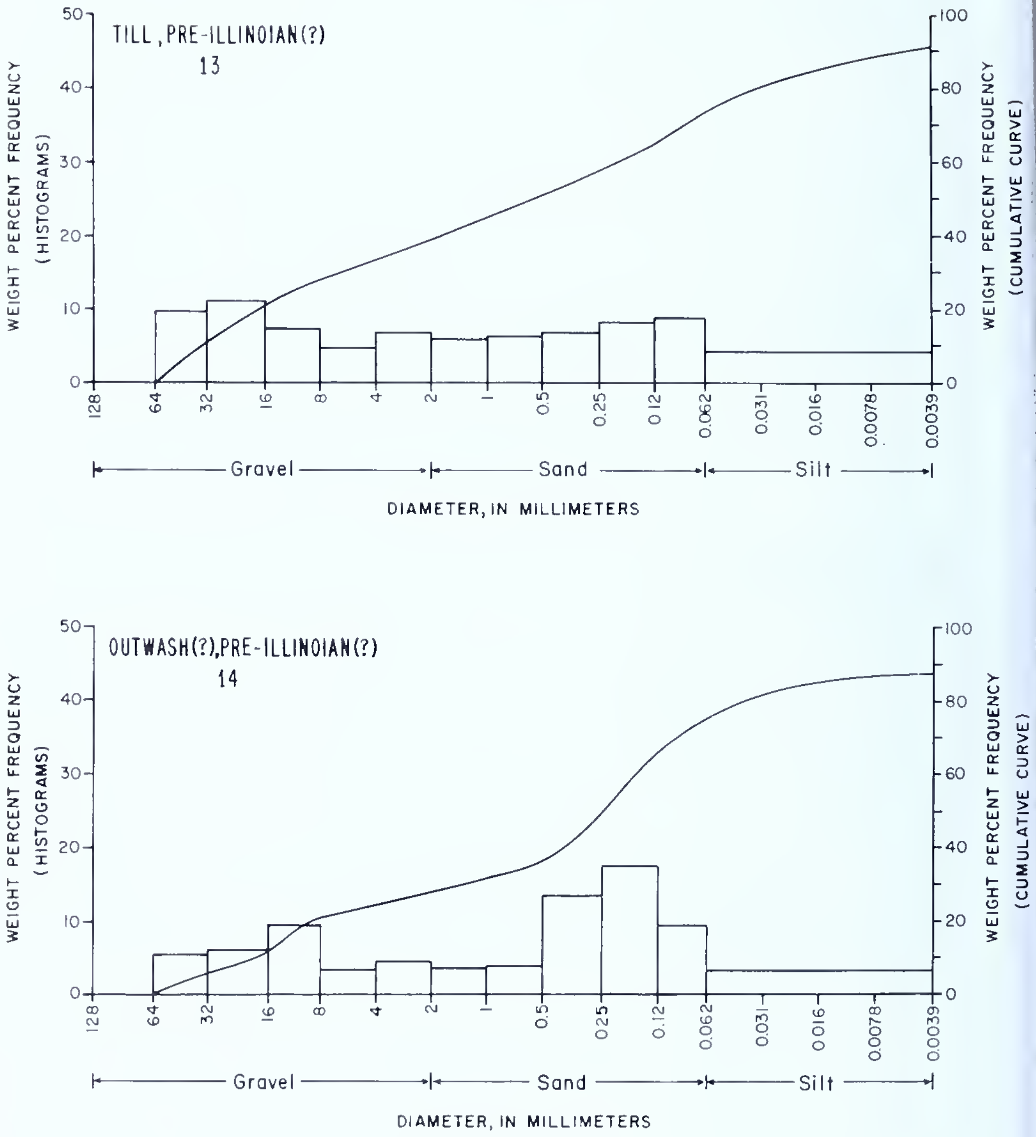


Figure 132. *(Continued)*

and pre-Illinoian(?) tills, as well as mixed colluvium and outwash, are very poorly sorted. Outwash of various ages is much better sorted than the till.

Figure 133 shows the lithic variations of the surficial deposits in the Palmerton quadrangle. The lithic names are given in Table 9. The diagram shows a clustering of the different deposits and shows that the tills and sample of colluvium contain a larger clay-silt fraction than the other deposits.

Table 9. *Percentages of Gravel, Sand, Silt, and Clay in Surficial Deposits in the Palmerton Quadrangle*

| Sample no. | Gravel | Sand | Silt | Clay | Lithic name | Comments |
|---|---|---|---|---|---|---|
| 1 | 2.2 | 72.2 | 15.8 | 9.8 | Slightly granular muddy fine sand | Alluvium; Lehigh River. Ten feet thick. Channel sample 3,300 ft. northwest of junction of Lehigh River and Aquashicola Creek. |
| 2 | .2 | 71.0 | 18.9 | 9.9 | Slightly pebbly muddy fine sand | Alluvium; Aquashicola Creek. Channel sample of upper 5 ft. 2,300 ft. northeast of junction of Lehigh River and Aquashicola Creek. |
| 3 | .2 | 88.9 | 9.6 | 1.3 | Slightly granular silty fine sand | Alluvium; Lehigh River. Much coal dust. Channel sample of upper 6 ft. Just east of village of Lehigh Gap. |
| 4 | 46.9 | 30.5 | 13.9 | 8.7 | Muddy sandy cobble gravel | Wisconsinan outwash. From trench at Palmerton sewage disposal plant. Boulders as much as 2.5 ft. long. |
| 5 | 75.9 | 19.5 | 2.8 | 1.8 | Muddy sandy cobble gravel | Wisconsinan outwash. Sample from 3 ft. below surface in pipeline trench. 3,300 ft. east of Walkton. Boulders as much as 2 ft. long. |
| 6 | 67.6 | 18.6 | 5.2 | 8.6 | Muddy sandy cobble gravel | Illinoian(?) outwash. Railroad cut, 400 ft. northwest of Delaware School in Palmerton. Rounded boulders as much as 1.5 ft. long. |
| 7 | 77.2 | 12.9 | 5.0 | 4.9 | Muddy sandy cobble gravel | Illinoian(?) outwash. Stream channel cut into Bloomsburg Red Beds and Lizard Creek Member of Shawangunk Formation at altitude of 420 ft. 1,000 ft. northwest of junction of Lehigh River and Aquashicola Creek. Boulders as much as 1.5 ft. long. |
| 8 | 23.2 | 26.7 | 36.9 | 13.2 | Pebbly sandy silt | Illinoian(?) outwash. Cobbles as much as 8 in. long. Probably mixed with colluvium. Northwest corner of intersection of 8th St. and Franklin Ave., Palmerton. |
| 9 | 34.3 | 11.1 | 32.8 | 21.8 | Muddy cobble gravel | Mixed Illinoian(?) outwash and colluvium. Cobbles as much as 6 in. long. Cut in dirt road in Aquashicola. |
| 10 | 36.3 | 29.3 | 16.4 | 18.0 | Muddy cobble gravel | Illinoian(?) till in borrow pit. Boulders as much as 4 ft. long. 800 ft. north of borough boundary of Walnutport. |
| 11 | 56.8 | 21.6 | 11.5 | 10.1 | Muddy sandy cobble gravel | Illinoian(?) till, 4 ft. below surface in pipeline trench. Boulders as much as 2 ft. long. 5,000 ft. southwest of Danielsville. |
| 12 | 31.0 | 18.3 | 23.3 | 27.4 | Muddy cobble gravel | Illinoian(?) till, 4 ft. below surface in pipeline trench. Boulders are as much as 1 ft. long. |
| 13 | 39.0 | 35.6 | 16.3 | 9.1 | Muddy sandy pebble gravel | Pre-Illinoian(?) till immediately below pre-Illinoian(?) stratified drift. Boulders as much as 5 ft. long. Cut in lot 1 mile north of Walnutport. |
| 14 | 27.9 | 47.1 | 12.3 | 12.7 | Pebbly muddy fine sand | Pre-Illinoian(?) stratified drift (outwash?). Three-ft. channel sample above till (sample 13). Cut in lot 1 mile north of Walnutport. |

## Table 10. *Statistical Parameters of Surficial Deposits in the Palmerton Quadrangle*

See Table 9 for comments. Md, median diameter; $Q_1$, first quartile; $Q_3$, third quartile; So, sorting coefficient $= \sqrt{Q_3/Q_1}$; Skg, geometric skewness $= \sqrt{Q_1Q_3/Md^2}$; $\log_{10}$Skg, when Skg 1, the log of the reciprocal is used and given a negative sign (see Krumbein and Pettijohn, 1938, p. 237); $P_{90}$, ninetieth percentile; $P_{10}$, tenth percentile; Kqa, arithmetic quartile kurtosis $= (Q_3 - Q_1)/2(P_{90} - P_{10})$; Ma, arithmetic mean of the diameter distribution; $\sigma$a, arithmetic standard deviation.

| Sample no. | Md (in mm) | $Q_1$ (in mm) | $Q_3$ (in mm) | So | $\log_{10}$So | Skg | $\log_{10}$Skg | $P_{90}$ (in mm) | $P_{10}$ (in mm) | Kqa | Ma | $\sigma$a |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.19 | 0.061 | 0.42 | 2.6 | 0.42 | 0.84 | −0.074 | 0.82 | 0.0050 | 0.22 | 0.42 | 0.90 |
| 2 | .13 | .05 | .29 | 2.4 | .38 | .93 | − .033 | .45 | .0039 | .27 | .23 | 14 |
| 3 | .20 | .11 | .31 | 1.7 | .23 | .92 | − .035 | 5.2 | .52 | .021 | .26 | .029 |
| 4 | 1.2 | .10 | 18 | 13 | 1.1 | 1.1 | + .049 | 80 | .015 | .15 | 19 | 32 |
| 5 | 41 | 2.1 | 92 | 6.6 | .82 | .34 | − .47 | 110 | .60 | .41 | 48 | 42 |
| 6 | 50 | .90 | 94 | 10 | 1.0 | .034 | −1.5 | 110 | .0053 | .49 | 48 | 44 |
| 7 | 42 | 2.9 | 83 | 5.4 | .73 | .14 | − .87 | 105 | .063 | .38 | 48 | 42 |
| 8 | .061 | .011 | 1.4 | 12 | 1.1 | .20 | − .69 | 11 | .0025 | .063 | 2.6 | 7.1 |
| 9 | .030 | .005 | 7.0 | 37 | 1.6 | 6.2 | + .80 | 16 | — | — | 7.1 | 8.6 |
| 10 | .27 | .02 | 10 | 23 | 1.4 | 1.7 | + .22 | 51 | — | — | 12 | 5.0 |
| 11 | 6.3 | .12 | 70 | 24 | 1.4 | .46 | − .34 | 110 | .0037 | .32 | 34 | 41 |
| 12 | .060 | .0029 | 21 | 85 | 1.9 | 4.1 | + .61 | 110 | — | — | 24 | 40 |
| 13 | .58 | .062 | 11 | 13 | 1.1 | 1.4 | + .15 | 32 | .0053 | .17 | 8.9 | 15 |
| 14 | .23 | .063 | 3.3 | 7.2 | .86 | 1.9 | + .30 | 17 | — | — | 5.5 | 12 |

## Table 11. *Average Statistics of Surficial Deposits in the Palmerton Quadrangle*

(Terms defined in Table 10)

| | Number of samples | Md | So | $\log_{10}$So | Skg | $\log_{10}$Skg | Kqa | Ma | $\sigma$a |
|---|---|---|---|---|---|---|---|---|---|
| Alluvium | 3 | .17 | 2.2 | .34 | .90 | −0.045 | .17 | .30 | 5.0 |
| Wisconsinan outwash | 2 | 27 | 9.8 | .99 | .72 | − .14 | .28 | 36 | 37 |
| Illinoian(?) outwash | 2 | 46 | 7.7 | .89 | .087 | −1.9 | .44 | 48 | 43 |
| Illinoian(?) outwash mixed with colluvium | 2 | 46 | 25 | 1.4 | 3.2 | + .51 | — | 4.9 | 7.9 |
| Illinoian(?) till | 3 | 2.2 | 44 | 1.6 | 2.1 | + .32 | — | 23 | 29 |
| Pre-Illinoian(?) till | 1 | .58 | 13 | 1.1 | 1.4 | + .15 | .17 | 8.9 | 15 |
| Pre-Illinoian(?) outwash(?) | 1 | .23 | 7.2 | .86 | 1.9 | + .30 | — | 5.5 | 12 |

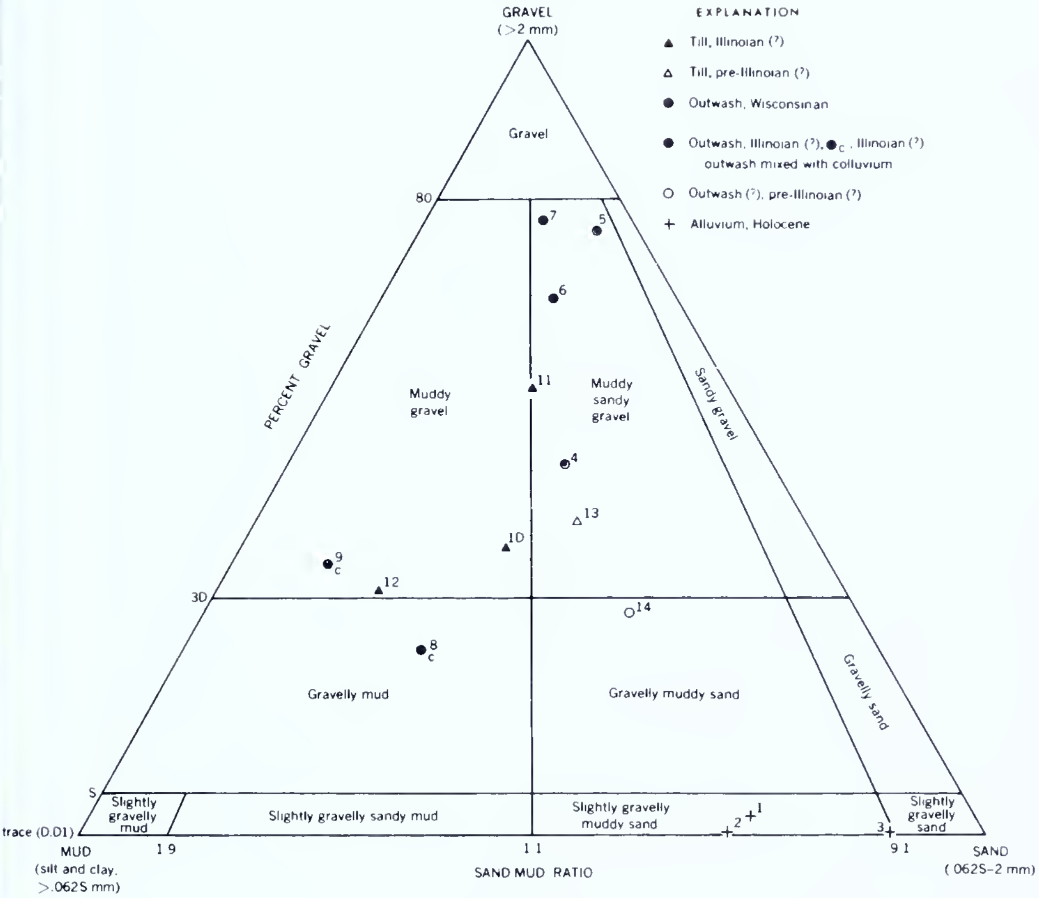


Figure 133. Ternary diagram showing textural variation of surficial deposits in the Palmerton quadrangle. Numbers refer to sample localities shown on Plate 2. The diagram has been modified from Folk (1954, Figure 1a, p. 346) in the following ways: (1) an arithmetic scale for percent of gravel is used for ease of plotting; and (2) composition fields for less than a trace (0.01 percent) of gravel are omitted, as all samples collected contain more than a trace.

## X-Ray Analyses

The mineralogy of the clay-sized fraction of 14 samples of surficial deposits was determined by X-ray diffraction techniques. The treatment of the samples and the methods of preparation and identification are given by Epstein (1969). The mineralogy is given in Table 12. There is a definite trend in the Stroudsburg quadrangle to the east where more Wisconsinan till and stratified drift are found. The Wisconsinan deposits contain abundant and well-defined chlorite, whereas kaolinite and vermiculite are absent or occur in small amounts. In Illinoian(?) and pre-Illinoian(?) deposits, chlorite is either absent or is identified by low and broad peaks, and kaolinite and vermiculite are generally abundant. Illite (clay-sized muscovite) is present in all samples, but it is slightly

Table 12. *Mineralogy of Clay-Sized Fraction of Surficial Deposits in the Palmerton Quadrangle as Determined by X-ray Diffraction Analysis*

Most samples contain traces of hematite and (or) goethite and feldspar. X, abundant, identified by prominent peaks; x, present, identified by peaks of moderate intensity; o, trace or possibly present, identified by very low or broad peaks.

| Sample no. | Age and rock type | Chlorite | Kaolinite | Vermiculite | Illite | Quartz |
|---|---|---|---|---|---|---|
| 1 | Holocene alluvium | | | X | X | X |
| 2 | do. | X | x | x | X | X |
| 3 | do. | | x | x | X | X |
| 4 | Wisconsinan outwash | X | | | X | X |
| 5 | do. | X | x | x | X | X |
| 6 | Illinoian(?) outwash | x | x | x | X | X |
| 7 | do. | x | o | x | X | X |
| 8 | Illinoian(?) outwash and colluvium | x | x | X | X | X |
| 9 | do. | | X | X | X | X |
| 10 | Illinoian(?) till | | o | X | X | x |
| 11 | do. | | X | X | X | x |
| 12 | do. | x | X | X | X | X |
| 13 | pre-Illinoian(?) till | | X | X | X | X |
| 14 | pre-Illinoian(?) outwash(?) | | X | X | X | x |

more degraded in the older deposits (less intense and more poorly defined characteristic 2M muscovite peaks). These features undoubtedly represent the effects of more prolonged weathering of the older deposits. The disintegration of chlorite and formation of kaolinite and the degradation of illite were noted in the weathering of Lower and Middle Devonian rocks near Kunkletown, Pennsylvania, 7 miles east of the Palmerton quadrangle, by Epstein and Hosterman (1969). Weathering of illite to form vermiculite was noted in tills in Ohio (Wilding and others, 1969). The clay minerals in the alluvium in the Palmerton quadrangle were undoubtedly inherited from local glacial drift and weathered bedrock, hence their diversity.

## STRUCTURAL GEOLOGY

The structural grain in the Lehighton and Palmerton quadrangles trends about N70E. Folds are the dominant structural features; faults are of regional importance but are subordinate. Cleavage, joints, and some lineations are important minor structures. All these structural features are shown on the geologic map and cross sections (Plate 1).

Earlier workers in the area generally depicted the structure as consisting of somewhat simple open folds (Rogers, 1858; Chance, 1882a; Hill, 1887; Johnson and others, 1933), although Behre (1933) correctly illustrated the complicated folding in the Martinsburg Formation. Epstein and Epstein (1967, 1969) showed that many of the rocks in easternmost Pennsylvania are parts of four lithotectonic units, that is, four rock sequences having dissimilar lithology, thickness of the component formations, and competency, and having different styles of deformation. In the Delaware Water Gap area to the east, it is clear that each of these sequences has been deformed semi-independently of rocks above and below (Epstein, 1973), as detachments along basal shear planes and zones (or décollements) separate the lithotectonic units. This relationship extends to the Lehigh River where the structure is more complex. The lithotectonic units, their lithic types and thicknesses, and styles of deformation are listed in Table 13.

Two mechanisms formed the folds: (1) flexural folding, in which bedding was a determining factor and in which movement was either by slip between layers (flexural slip) or by flow within layers (flexural flow); and (2) passive folding, in which movement was along laminar-flow planes (passive flow) or slip planes (passive slip), and in which bedding was passive and merely indicates deformation in the direction of movement (see Donath and Parker, 1964). Flexural-slip folding in the area is characterized by extensive development of bedding-plane slickensides and by maintenance of constant orthogonal bedding thickness in all parts of the fold, whereas in flexural-flow folding, thickness perpendicular to bedding is not constant. Passive folds have the shape, or form, of similar folds and constant axial-plane thicknesses (the length between bedding planes measured along cleavage, if cleavage is parallel or subparallel to the axial planes, for example) are generally maintained. If the planes of movement (the cleavage planes) are macroscopically discontinuous, the folding is by passive slip, but if the movement planes are so closely spaced as to be indistinguishable to the unaided eye, the folding is termed passive flow.

The spatial and age relations and the structural features that were produced during the various orogenies in eastern Pennsylvania have been discussed and argued for more than 100 years. Most of the structures in the Lehighton and Palmerton quadrangles are interpreted to be of Appalachian (late Paleozoic) age, although in the Martinsburg Formation these may be superimposed upon the upright limb of a large complex regional overfold, the Musconetcong nappe, that was a product of the Middle-Late Ordovician Taconic deformation. Taconic orogenesis also produced the coarse Silurian clastic wedge that rests unconformably on the Martinsburg. Clastics of the Catskill Formation and younger

Table 13. *Lithotectonic Units and Décollements in the Lehighton and Palmerton Quadrangles*

| Lithotectonic unit | Age of lithotectonic unit and stratigraphic sequence | Lithologic characteristics | Type of folds | Average size of folds |
|---|---|---|---|---|
| 4 | Pennsylvanian to Middle Devonian Pottsville Formation to Marcellus Formation | More than 15,000 feet of sandstone, conglomerate, siltstone, and shale | Asymmetric, concentric, flexural slip, and passive slip. Broad open folds | Wavelength about 5 miles and amplitudes more than 3,500 feet |
| Weir Mountain décollement | | | | |
| 3 | Middle Devonian to Upper Silurian<br>Marcellus Formation to Poxono Island Formation | About 1,050 feet of shale, limestone, sandstone, and dolomite; heterogeneous stratigraphic units between about 8 and 100 feet thick | Asymmetric, concentric, and similar, flexural slip and flow, passive slip and flow. Flap folds | Wavelengths average about 1,500 feet; amplitudes about 1,000 feet |
| Stony Ridge-Godfrey Ridge décollement | | | | |
| 2 | Upper Silurian to Upper Ordovician(?)<br>Bloomsburg Red Beds and Shawangunk Formation | About 3,200 feet of sandstone, siltstone, shale, and conglomerate; coarser toward base of sequence | Asymmetric, concentric; flexural and passive slip. (Bedding slip and wedge faulting in the Bloomsburg Red Beds) | Wavelengths average about 4,500 feet; amplitudes about 2,000 feet |
| Blue Mountain décollement | | | | |
| 1 | Upper and Middle Ordovician Martinsburg Formation | More than 8,000 feet of slate and graywacke | Asymmetric, similar; mainly passive slip and flow; flexural slip near contact with Shawangunk Formation. Folds probably superimposed on upright limb of large regional nappe | Wavelengths average about 1,000 feet; amplitudes about 600 feet |

rocks indicate the Devonian Acadian orogeny; structural evidence is lacking but may be present under cover.

In the following pages, Epstein has described the décollements and structures in lithotectonic unit 1 through the lower part of unit 3, and Sevon has described the structures in the upper part of lithotectonic unit 3 through unit 4.

## DÉCOLLEMENTS

Disharmonic folding was caused by lithic variations within each lithotectonic unit (see cross sections on Plate 1). The difference in shortening between adjacent lithotectonic units is believed to have been taken up in incompetent rocks along bounding discontinuities or décollements (Epstein and Epstein, 1967, 1969; Epstein, 1973). Movement of overriding plates on the décollements was to the northwest, as interpreted from fold geometry and minor structural features. Axes of many folds do not cross lithotectonic unit boundaries.

Shortening, in competent units apparently deformed mainly by flexural slip, was measured by comparing the distance between two points along bedding to the straight-line distance between the same points in section as described by Cloos (1940). Shortening averages about 24 percent in lithotectonic unit 2, about 42 percent in lithotectonic unit 3, and about 10 percent in lithotectonic unit 4. The shortening in units 2 and 3 may be nearly twice as much as indicated if the inferred buried syncline along the Sweet Arrow fault (see cross sections B-B′, D-D′, and E-E′, Plate 1) is considered in the computations. Shortening due to faulting was not considered.

Wood and Bergin (1970) described five lithotectonic units in the anthracite region of eastern Pennsylvania; they included the Lehighton and Palmerton quadrangles in the eastern part of their area of discussion. Their lithotectonic unit 1 comprises units 2 and 3 of this report, and they divide lithotectonic unit 4 of this report by décollements near the top of the Mauch Chunk Formation (Pottchunk fault) and near the bottom (Mauchono fault) (see also Wood and others, 1969) and also by structural differences above and below the base of the Catskill Formation.

The Blue Mountain décollement separates rocks of the Martinsburg and Shawangunk Formations. It is exposed at Lehigh Gap along the abandoned Lehigh and New England Railroad grade. There, the décollement is a zone about 8 inches thick underlying about 2 inches of unsheared Martinsburg that is in contact with the overlying Shawangunk Formation. From bottom to top the zone consists of slickensided quartz and sheared slate (2-3 inches thick), fault gouge of Martinsburg fragments as much as 2 inches long in a clay matrix (2 inches thick), and breccia (3-4 inches thick). In the slickensided bed, northwest movement of overriding beds is indicated by small drag folds and faults (Figure 134) and by microscarps or steps on the slickensided surfaces. Relations between the slickensides, drag folds, and cleavage indicate that the cleavage developed synchronously with movement on the décollement.

It is impossible to determine the amount of displacement on the Blue Mountain décollement. However, based on inferences from the Stony Ridge-Godfrey Ridge décollement zone, displacement could be thousands

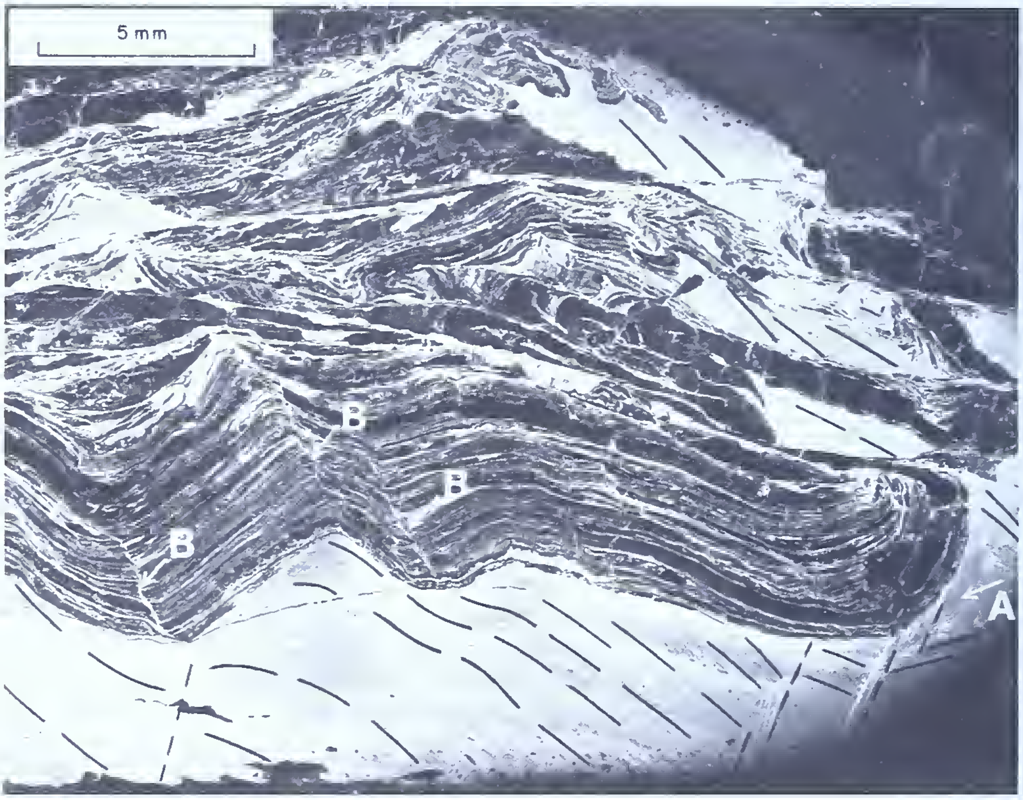


Figure 134. Negative print of thin section from 2- to 3-inch-thick slickensided interval in Blue Mountain décollement, 8 inches below contact of Martinsburg and Shawangunk Formations, along abandoned Lehigh and New England Railroad grade. Northwest is to the left. Dark laminae are folded and faulted quartz slickensides. The drag folds are overturned to the northwest and displacement of upper plates on small faults is to the northwest, corroborating the movement indicated by steps on slickensides. Long dashes are traces of slaty cleavage; short dashes are traces of slip cleavage. Absence of slaty cleavage in strain shadow at trough of fold (at A) and arching of cleavage of folded northwest limb of the fold suggest that cleavage developed synchronously with and slightly earlier than the folding but during the same deformation. Pelitic material is intruded through the quartz slickensides at a steeper angle to cleavage in the surrounding shale and parallel to the axial planes of the folds (at B). Note divergent fanning of cleavage on either side of the fold trough.

of feet or as much as miles. Large displacement is also indicated by the fact that the source for the pebbles in the Shawangunk, as described under the section on environments of deposition of the Shawangunk Formation, could not have been entirely the underlying rocks. This implies that the Shawangunk has traveled many miles away from its source terrain on the Blue Mountain décollement.

The sheared rocks in the décollement are weathered dark-yellowish orange (10YR5/6), reddish brown (10R3/4), and grayish red (5R4/2). They apparently were a zone for the movement of ground water. Clay from the fault gouge was X-rayed and found to contain quartz, muscovite, and kaolinite. The kaolinite apparently developed by weathering at the expense of chlorite, which is present in unweathered rock.

The Stony Ridge-Godfrey Ridge décollement zone separates lithotectonic units 2 and 3. The dramatic change in fold geometry, as seen on the geologic map and cross sections, takes place at or near the largely covered Poxono Island-Bloomsburg contact, but wedging and bedding slip in the Bloomsburg Red Beds of lithotectonic unit 2 suggest considerable northwest movement. As was described by Epstein and Epstein (1969) and will be described under lithotectonic unit 2, the net telescoping in the Bloomsburg may amount to thousands of feet or many miles.

To account for the difference in fold geometry between lithotectonic units 3 and 4, the movement on the Weir Mountain décollement may have been taken up by extensive shear in the Marcellus Formation. Well-developed cleavage, distorted cleavage, and abundant faults in exposures along the Northeast Extension of the Pennsylvania Turnpike attest to this shearing (see Figure 161). However, as will be discussed later, much of this deformation may be related to the Sweet Arrow fault. In all likelihood, the Weir Mountain décollement comes to the surface in the core of the Lehighton anticline where cleavage is the dominant planar element and bedding is obscured in many places. A faulted and greatly thickened section of the Marcellus Formation was encountered in the subsurface about 2,000 feet south of the crest of the Lehighton anticline in the Phillips Petroleum Company exploration well No. 1 Graver Estate (see measured section 24). This indicates that the Weir Mountain décollement and possibly imbricate thrusts that have sheared off the décollement are present in the subsurface. The southeast-dipping fault between the Beaverdam Run and Long Run Members of the Catskill Formation, in the northwest part of the Lehighton quadrangle, may be an imbricate fault that intersects the décollement in the subsurface. Immediately to the west of the quadrangle, G. H. Wood, Jr. (oral commun., 1972), has interpreted the fault in this way.

Several other explanations for the disharmonic relations between lithotectonic units 2, 3, and 4 are possible. First, the folds in lithotectonic unit 3 may be the result of drag on the Sweet Arrow fault, as can be interpreted from Wietrzychowski (1963b). However, these folds are not considered by the authors to result from drag along a fault, because they do not die out southeast of the hypothetical fault. This is evident 6 miles east of the Palmerton quadrangle in the Kunkletown area where the complex folds are found more than 1 mile southeast of the position of the Sweet Arrow fault, if it were extended along strike to that place. Moreover, the Sweet Arrow fault apparently dies out west of Kunkletown.

Kehle (1970) has described another possibility that could be used to interpret lithotectonic unit 3 as a décollement zone, an explanation whereby the movement of overlying rocks (lithotectonic unit 4) and underlying rocks (lithotectonic unit 2) is taken up by shear within the décollement zone. Another possibility is that there has been no relative movement between the lithotectonic units and that the disharmony is the result of buckling of a series of layers of different competencies or viscosities (for example, Ramsay, 1967, p. 380) ; thus, no relative differences in shortening need have taken place.

The interpretation of décollements separating the lithotectonic units is favored over the last two alternative possibilities because of evidence of northwest movement of rocks as mentioned above. Also, the axial planes of parasitic folds that develop during buckling of competent units in layers of variable thickness dip away from the crest of the larger fold to which they are satellitic (Ramberg, 1964, p. 322). The axial planes of the folds in lithotectonic unit 3 do not have this relation to the larger folds in lithotectonic unit 4. The axial planes of the folds everywhere dip to the southeast, except where they are warped to the northwest. This situation is clearer to the east in the Stroudsburg area where the structure is not as complex (Epstein, 1973) . The preferred décollement hypothesis is also in harmony with similar interpretations in the Appalachians elsewhere in Pennsylvania (Gwinn, 1964b, 1970; Wood and Bergin, 1970) and accepted in the regional synthesis of the structure of the Valley and Ridge province of eastern Pennsylvania by Gwinn (written commun., 1967) . Fitzgerald and Braun (1965) and Dahlstrom (1969) presented similar examples of detachments separating units of different structural styles in British Columbia, Canada.

The décollements in the Lehighton and Palmerton quadrangles are folded but dip to the northwest on a regional scale. No obvious root zone is known. Therefore, northwest movement into the Appalachian basin may have been primarily by gravitational movement from uplifted areas to the southeast, although it was probably aided by northwest-directed tectonic forces.

## LITHOTECTONIC UNIT 1

The Martinsburg Formation of Ordovician age forms lithotectonic unit 1. Folding is complex, as was shown by many workers, including Sanders (1883) and Behre (1933). Passive folding was the dominant mechanism of deformation, although bedding-plane slickensides are locally offset by cleavage (Figure 135), indicating that the Martinsburg was competent enough during the early phases of folding to have failed by flexural slip, whereas later, as deformation (and presumably ductility) increased in intensity, the rock failed plastically with the development of cleavage. In some localities, there is evidence that cleavage may have developed more or less simultaneously during flexural slip (Figure 134); this indicates that not all of the Martinsburg behaved plastically at the same time.

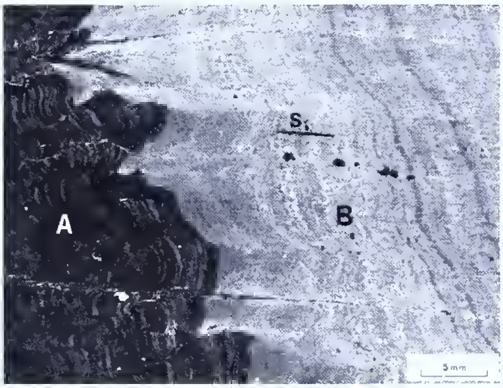


Figure 135. Bedding-plane slickensides (A) and laminated calcareous and carbonaceous slate (B) offset by slaty cleavage ($S_1$). Note the coarser cleavage and greater offset in the slickensides. The slickensides are composed of calcite (dark laminae) and pelitic material (lighter laminae). Some pelitic material has intruded through the slickensides into the surrounding slate. The relations of slickensides and cleavage show that flexural-slip folding preceded passive folding. Negative print of acetate peel of sample from the Pen Argyl Member of the Martinsburg Formation, quarry of Penn Big Bed Slate Company, 6,000 feet west of Rextown and 300 feet south of the Lehighton quadrangle, in the Slatedale quadrangle.

Axial planes of the folds in lithotectonic unit 1 dip on the average about 50SE, and the axes plunge about 3° S75W. Slaty cleavage[1] is the most dominant planar feature, although it is less prominent than bedding within a few hundred feet of the overlying Shawangunk Formation. The cleavage fans the folds from a few degrees to as much as 45° (Figures 2, 136, 137).

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[1] Slaty cleavage, and slip cleavage which is locally developed, in lithotectonic units 1-3 is discussed under a separate heading later in this report.

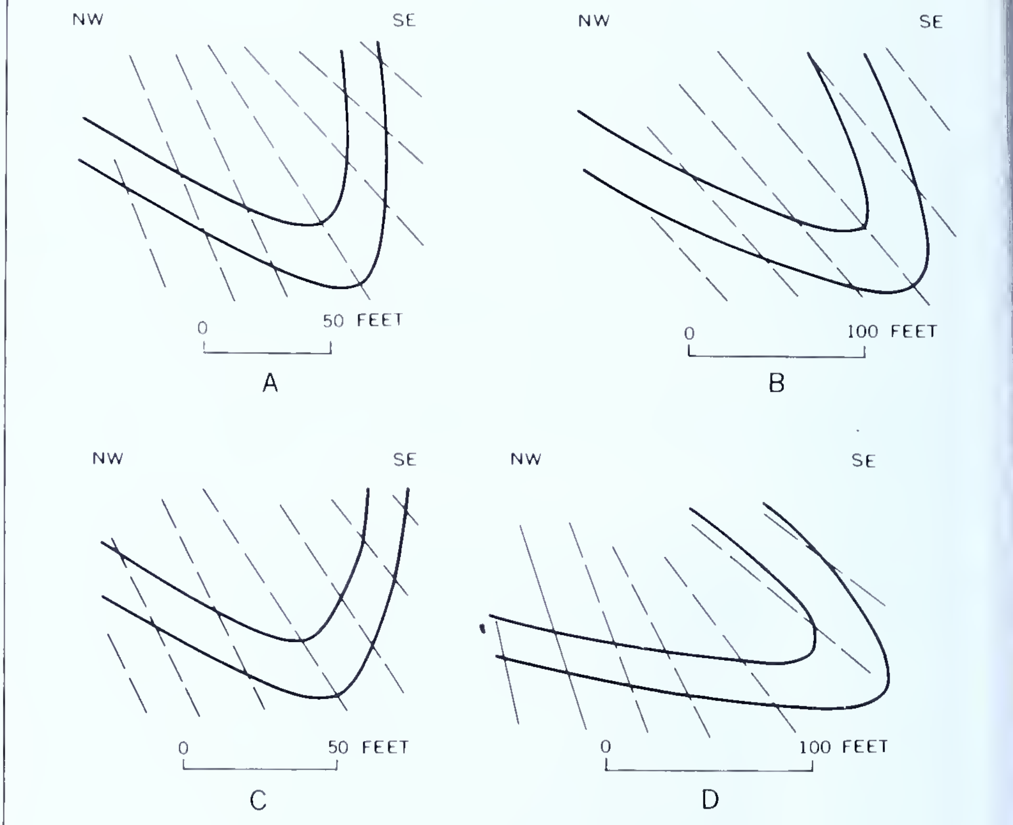

Figure 136. Cross sections of folds exposed in abandoned slate quarries in the Pen Argyl Member of the Martinsburg Formation (lithotectonic unit 1) in the Palmerton quadrangle, showing fanning of slaty cleavage (dashed lines). A. Gem quarries, 2,600 feet southeast of Danielsville, 25° fan; B. Parry and unnamed quarry, 4,300 feet northeast of Bassards Corner, 2° fan; C. Rudolf quarry, 4,800 feet west of Berlinsville, 12° fan; D. Fullmer quarry, 1,300 feet north of the Third Ward School in Slatington, 45° fan.

Slaty cleavage may not fan a fold symmetrically because limbs were differentially rotated during later stages of development so as to alter the original shape of the fold. The rate and direction of movement along the flow lines or planes of transport (the cleavage planes) may not be constant with time, resulting in disharmony in the otherwise similar folds. As shown in Figure 138, the overturned limb in the similar fold (A) may migrate by unsteady flow toward the direction of the retarded syncline (B) or away from the syncline (C). At the same time that the fold in C develops, the rate of flow in the lower limb may become nonuniform, resulting in folding of that limb while the upper limb is being rotated (D). Examples of the fold shown in Figure 138A are numerous

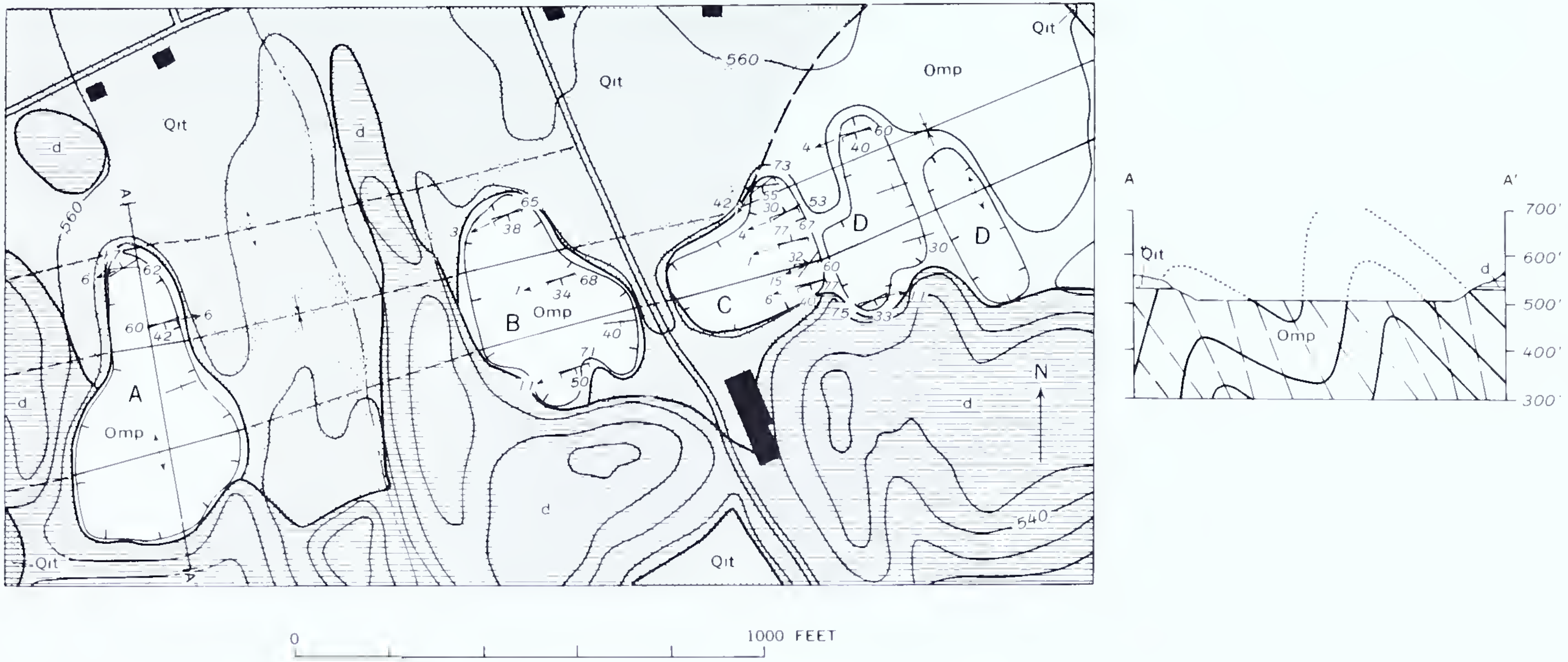

Figure 137. Geologic map and section of the abandoned Blue Valley (A), Eureka (B), Mountain (C), and Pittstown quarries (D), 3,500 feet northeast of Rextown in the southeast corner of the Lehighton quadrangle. Dashed lines in cross section are trace of cleavage which fans the folds through an angle of about 24°. Geologic symbols are the same as for the geologic map, Plate 1. Photograph of southernmost anticline is shown in Behre (1933, p. 309).

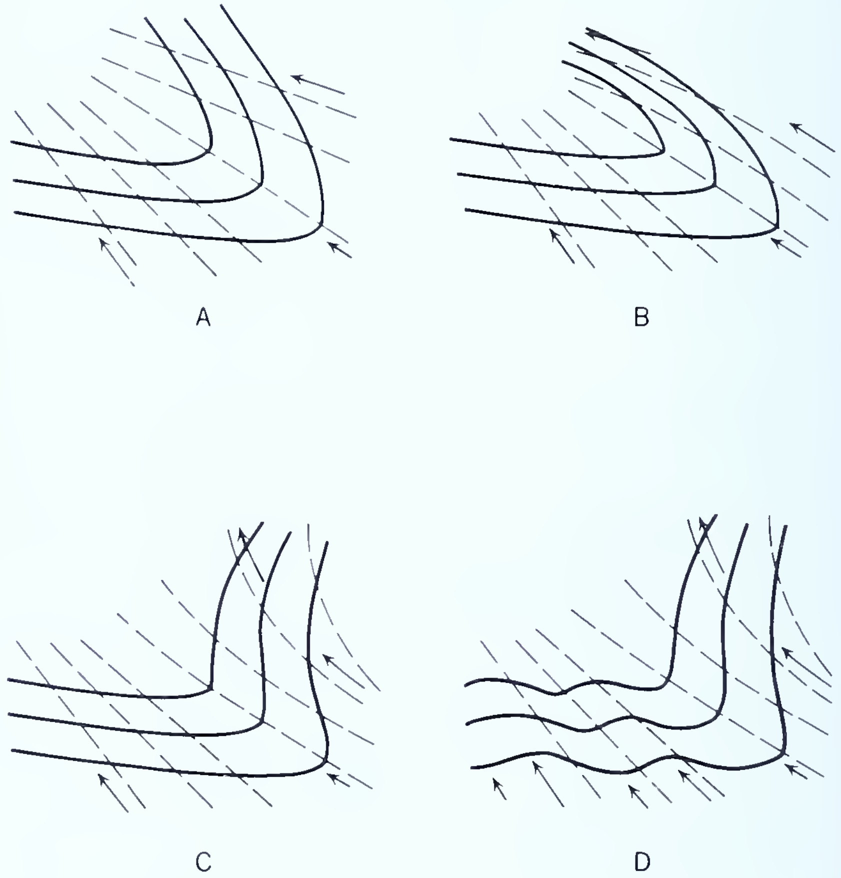

Figure 138. Stages in development of disharmonic similar folds by changing transport direction and rate, as discussed in text. Dashed lines are cleavage, arrows indicate flow or transport directions, length of arrows indicate relative amount of flow.

(see Figures 2 and 136A, B, C). Examples of the fold in Figure 138B are shown in Figures 136D and 139. Examples of clockwise rotation of overturned limbs, as depicted in Figure 138C, are found in outcrops along the Northeast Extension of the Pennsylvania Turnpike 1,000 feet east-northeast of Rextown in the Lehighton quadrangle and in a borrow pit 1 mile north of Walnutport in the Palmerton quadrangle. The structure in the borrow pit is shown in Figure 140.

The conclusion that may be drawn from the examples above is that refolded folds may form by unsteady flow and synchronous refolding, as was described by Wynne-Edwards (1963), and not necessarily only by fold superposition during two periods of orogeny, as may be interpreted

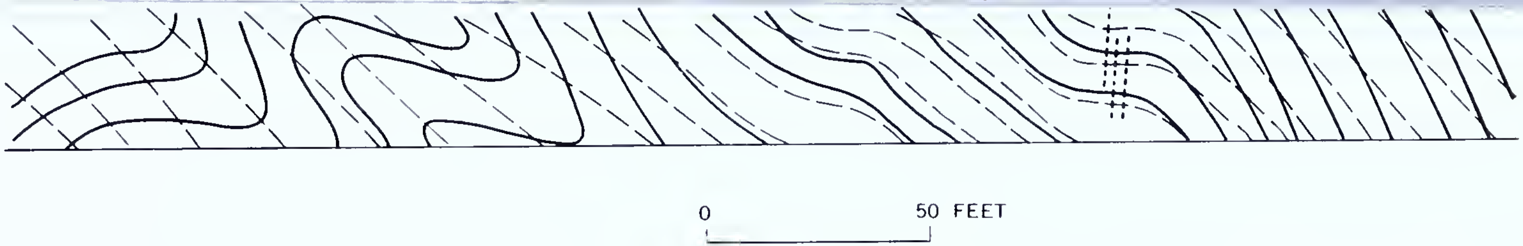

Figure 139. Folds in slate of the Martinsburg Formation along the Central Railroad of New Jersey, 3,000 feet south of Lehigh Gap. Solid lines are bedding, long dashed lines are slaty cleavage, and short dashed lines are slip cleavage. Note the parallelism and counterclockwise rotation of bedding and cleavage in the overturned limb on the south and the slip cleavage that developed in the cleavage arch. The axis of the cleavage arch trends 26° N69E.

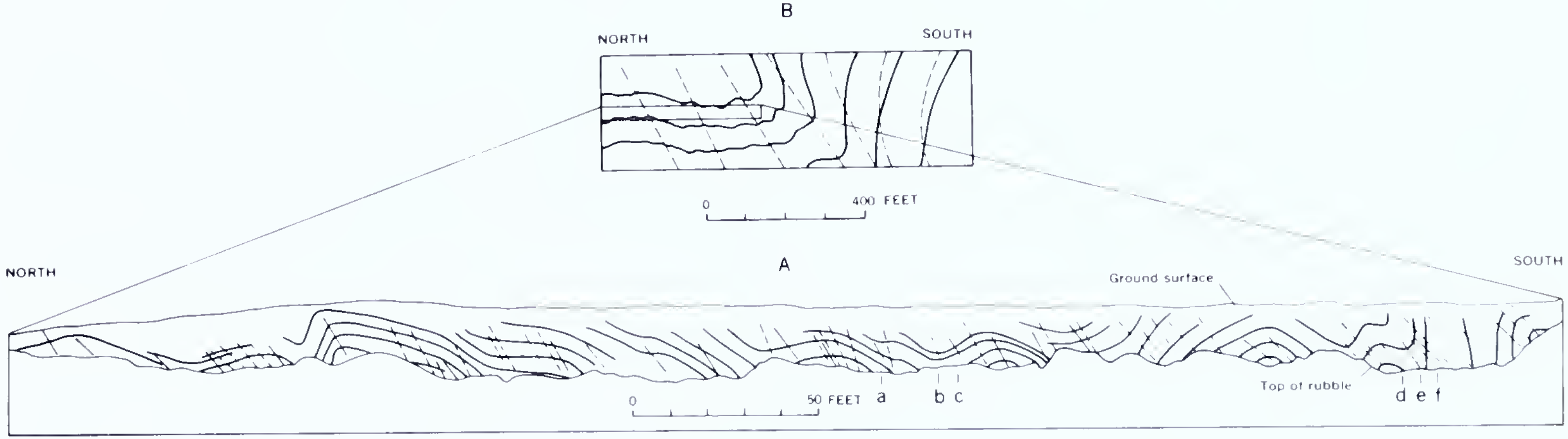

Figure 140. Folds in the Pen Argyl Member of the Martinsburg Formation. A. Sketch from photograph (corrected for foreshortening) of outcrop in borrow pit along Pa. Route 145, 1 mile north of Walnutport. Solid southeast-dipping lines are traces of cleavage measured in the outcrop; dashed lines are traces of cleavage taken from photograph. B. Cross section of larger fold showing small folds in A superimposed on northwest upright limb and rotated bedding and cleavage in overturned southeast limb. Orthogonal thicknesses of beds and lengths of beds along cleavage (the "split") were measured on the limbs and troughs of two folds (a, b, c, and d, e, f). These measurements are shown in Table 14.

for the fold pattern in Figure 140. The argument against two distinct periods of deformation for the structural relations in Figure 140B is that the upper limb of the fold does not have the small folds superimposed on it as does the lower limb. Also, an argument for continuous deformation is that the length of beds measured along cleavage (the "split" of quarrymen) is fairly constant in different parts of an individual fold, which is to be expected when the same flow lines are used during continuous folding (see Carey, 1962), and may not be true if flow lines of separate deformations are at an appreciable angle to each other. The "split" and orthogonal thickness of beds in two folds shown in Figure 140A is given in Table 14.

Faults of large displacement have not been recognized in lithotectonic unit 1. They may be present, but discontinuous exposures and lack of key beds would preclude their recognition. No major faults appear to have offset the contact between the Pen Argyl and Ramseyburg Members. Two small high-angle faults have been observed. One, in which the shear zone containing abundant vein quartz is 5-8 feet wide, is shown on Plate 1 along the Northeast Extension of the Pennsylvania Turnpike just south of the contact with the Shawangunk Formation. The other, just south of the Lehighton quadrangle, is shown in Figure 2.

Table 14. *Orthogonal Thickness of Beds and Split (Distance Between the Top and Bottom of a Bed or Beds Measured Along Cleavage) in Two Folds Shown in Figure 140.*

| | | Orthogonal thickness (in inches) | Split (in inches) |
|---|---|---|---|
| | a | 3.0 | 5.7 |
| Fold 1 | b | 5.3 | 5.4 |
| | c | 5.9 | 5.9 |
| | d | 1.7 | 3.0 |
| Fold 2 | e | 3.1 | 3.1 |
| | f | 2.4 | 3.1 |

## LITHOTECTONIC UNIT 2

The rocks in lithotectonic unit 2 are chiefly competent rigid sandstone and conglomerate in the lower part (Shawangunk Formation) and interbedded sandstone and less competent siltstone and shale in the upper part (Bloomsburg Red Beds). The unit deformed mainly by flexural slip, and bedding-plane slickensides are abundant. Slaty cleavage and commonly a later slip cleavage are found in nearly all pelitic rocks. Cleavage fans the larger folds, as seen in the overall map patterns, and the smaller folds (Figure 141). Mud cracks, which are abundant in the Bloomsburg Red Beds (see Figure 43), are elongated parallel to the

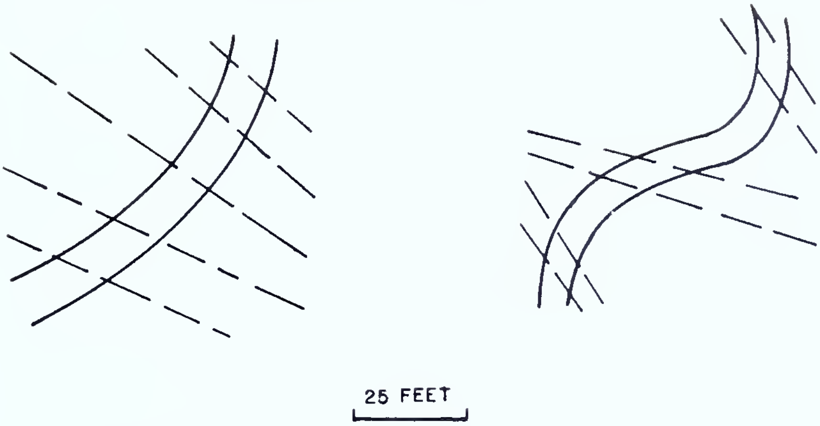

Figure 141. Cleavage fans in pelitic rocks of the Bloomsburg Red Beds near the sewage-disposal plant in Palmerton. Cleavage traces are dashed lines; solid lines are bedding. Cleavage diverges 20° and 43° in these examples.

structural grain. The polygons are about twice as long in the *b* tectonic direction as they are in *a*.

Many of the folds in lithotectonic unit 2 are recumbent (see cross sections, Plate 1), and some axial planes may dip to the northwest. The basis for this interpretation is that overturned beds in Blue Mountain merge fairly rapidly along the trend of the mountain into upright beds. If the axial planes of the folds had a moderate to steep dip to the southeast, then overturned and upright beds would appear on different sides of the mountain as the trace of the axial plane emerged along its plunge; but this is not the case. For example, upright beds are mostly exposed at Lehigh Gap, but beginning about 900 feet to the east overturned beds crop out or are interpreted to be present on the basis of topographic expression. Similarly, overturned beds are found at Little Gap, whereas only right-side-up beds are found 1 mile to the east.

Some of the beds at Little Gap are rotated more than 180° and dip northwestward. Figure 142 is a detailed cross section through Blue Mountain near Little Gap. The data are from unpublished mapping in the water tunnel for the city of Bethlehem, Pennsylvania, by B. L. Miller. In some strongly overturned strata in the Bloomsburg Red Beds, cleavage has been rotated to the northwest.

The traces of the axial planes of these recumbent folds are not shown on the geologic map because of the difficulty in depicting them and because of scattered exposures. The traces would trend at high angles to the strike of Blue Mountain. This may be compared with the more acute angle for more upright folds in the mountain about 16 miles to the northeast in the Stroudsburg quadrangle (Epstein, 1973).

Four small doubly overturned folds were mapped east of Lehigh Furnace Gap in the Shawangunk Formation. The rocks in beds that have

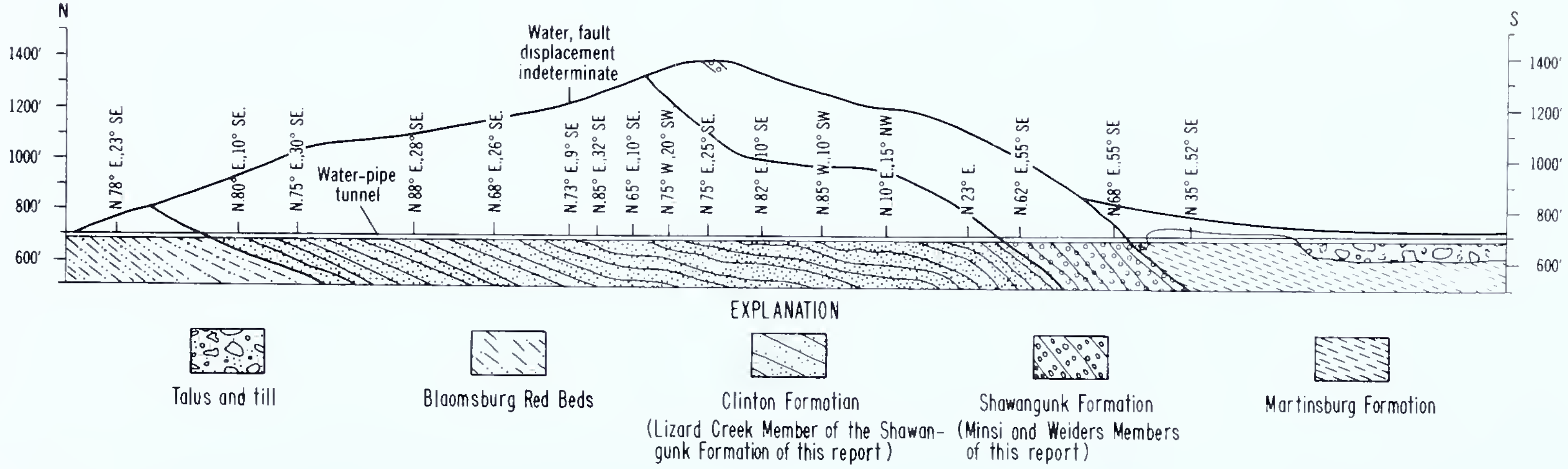

Figure 142. Cross section through Blue Mountain at Little Gap along water tunnel for the city of Bethlehem, Pennsylvania. Dips plotted are corrected to tunnel direction. Actual dips and strikes are recorded above section. All dips are overturned to southeast except northwest dips which are in beds that have been rotated more than 180°. Line of section is shown on Plate 1. Modified from unpublished data by B. L. Miller (1940).

been rotated more than 180° are highly sheared. Pressure solution was extensive in the sandstones and conglomerates and resulted in deeply embayed and stylolitic contacts between quartz grains (Figure 143). Elsewhere, grain boundaries are not as penetrative (see photomicrographs of rocks in the Shawangunk Formation in the section on stratigraphy).

The folds in lithotectonic unit 2 exposed in Lehigh Gap extend down through the Blue Mountain décollement into the Martinsburg Formation (see cross section E-E′, Plate 1). Chance (1882b) also interpreted the structure in this way. It is on the basis of this relationship that the more complex recumbent folds in lithotectonic unit 2 to the east are depicted as extending into the underlying Martinsburg in an area where exposures in the upper part of the Martinsburg are absent (see cross section G-G′, Plate 1). It is possible, however, that the folds in lithotectonic unit 2 are tighter than in the underlying unit, having resulted from sliding of the rocks in the Shawangunk and Bloomsburg on the Blue Mountain décollement and folding of these rocks independently of the rocks below.

No major faults were mapped in lithotectonic unit 2 east of Lehigh Gap, and none were mapped between the Palmerton quadrangle and Delaware Water Gap 20 miles to the east. A small normal fault on the east side of Lehigh Gap offsets units 10 and 11 of section 3 (Epstein and Epstein, 1972, p. 31-41) in the Weiders Member of the Shawangunk Formation. This fault dips 53SE and has a displacement of about 10 feet.

Major faults are conspicuous in Blue Mountain west of Lehigh Gap. The largest one, the Lehigh Furnace Gap fault, has been mapped for more than 5 miles. It extends from under cover in the Martinsburg Formation on the southwest into the Bloomsburg Red Beds east of the Northeast

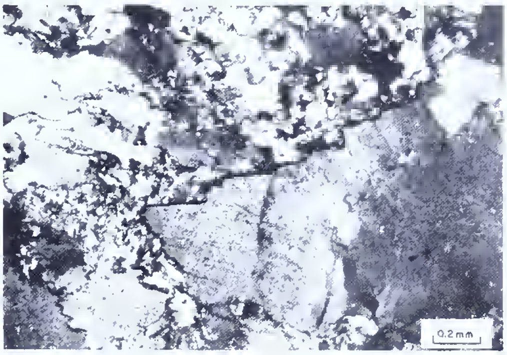

Figure 143. Photomicrograph (crossed polarizers) showing deep penetration contact along stylolitic seam between quartz grain with strongly undulose extinction on the right and grain of vein quartz on the left. A thin film of hematite lies along the stylolite. Conglomeratic quartzite in the Minsi Member of the Shawangunk Formation, 1,400 feet northeast of the radio tower at Lehigh Furnace Gap.

Extension of the Pennsylvania Turnpike and may underlie the Lehigh River for an unknown distance to the northeast. Maximum displacement is about 1,000 feet. Beds southeast of the fault have been rotated more than 180° in places, forming synformal anticlines and antiformal synclines (see cross section C-C′), and cleavage in the Bloomsburg Red Beds at the north portal of the Northeast Extension of the Pennsylvania Turnpike has been rotated to the northeast. These features suggest thrusting of the overturned limb of a fairly tight fold. The Lehigh Furnace Gap fault and its offshoot at Lehigh Furnace Gap dip to the northwest, judging from the geometry of the beds that are cut off and the relations of the trend of the faults to topography. The main fault is steeper and perhaps nearly vertical at Lehigh Furnace Gap and appears to have been rotated about a vertical axis there after it formed or during the later stages of its formation. The best places to see cutting out of beds are in the Lehigh Furnace Gap area and along the telephone line 1 mile east of the gap where southeast-dipping overturned beds of the Weiders Member of the Shawangunk Formation are in contact with the Lizard Creek Member.

Northwest movement of rocks in the Bloomsburg Red Beds, part of the Stony Ridge-Godfrey Ridge décollement zone, is indicated by abundant bedding-plane slickensides (Figure 45) and wedges (Figure 144). These features are well exposed in near-vertical beds in Lehigh Gap (Figure 48). The slickensides are in intervals as much as 1 inch thick which consist of sheared vein quartz and chlorite and which contain pelitic fragments from the surrounding rock. Bedding in the fragments is at all angles to local bedding. The fragments also contain disoriented cleavage, proving that the development of slickensides, at least partly, postdates cleavage development. Small steps or microscarps on nearly all slickensided surfaces clearly show that movement of overriding beds was downdip to the northwest, not updip as would be expected if the slickensides were due to flexural-slip folding. This northwest movement is corroborated by the wedges and drag of cleavage (Figure 145). Only two wedges at Lehigh Gap were seen that exhibit a reverse sense of movement (Figures 145D and E). These appear to have developed by movement of material out of folds above the slip surfaces and do not detract from the proof of overall direction of transport.

The amount of movement on one bedding-slip plane can be estimated by accumulating the displacement in all wedges. The net telescoping in the Bloomsburg was certainly thousands of feet, if not as much as some miles (Epstein and Epstein, 1969, p. 184). This estimate was arrived at by multiplying the number of bedding-slip surfaces in the Bloomsburg (128 were counted in the 900 feet of rock that is exposed at Lehigh Gap) by the estimated frequency of wedges along a single bedding-slip surface in

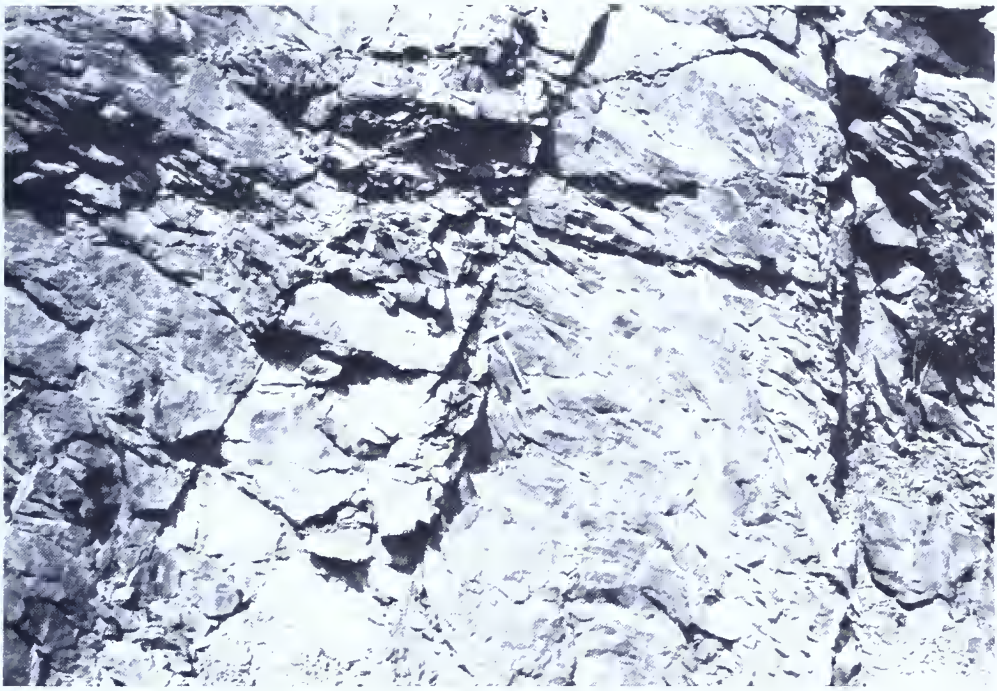

Figure 144. Wedge in the Bloomsburg Red Beds, Lehigh Gap, in roadcut along Pa. Route 248, about 1,300 feet north of Aquashicola Creek. Bottom of sandstone bed just above hammer is slickensided. The sandstone moved downdip to the northwest as indicated by steps in the slickensides. This direction of movement is corroborated by the wedge to the left of the hammer and by northwest dragging of the moderately dipping southeast cleavage at the slickensided surface. Compare with Figure 145A.

the updip direction, and by the estimated amount of displacement per wedge (it was assumed that there was 2 feet of displacement for every 100 feet along a slip surface in the dip direction, but some wedges were seen 20 feet apart with displacements of 2 feet each). The distance along which the beds dip to the northwest creating the necessary slope for sliding to have occurred is at least 1 mile and may be more than 4 miles (see cross section E-E′, Plate 1).

The estimated displacement parallel to bedding may not be unreasonable. As discussed under the section on décollements, the rocks in lithotectonic unit 3 have shortened considerably more than the rocks in unit 2. The greater shortening was taken up along the Stony Ridge-Godfrey Ridge décollement zone, and the slippage seen in the Bloomsburg reflects that movement.

In one outcrop of the Bloomsburg on the north slope of Blue Mountain northeast of Little Gap, where the beds are overturned and dip less than 30° southeast, slickensides indicate that the overlying beds moved to the southeast. This suggests that sliding ceased after the folds were overturned, resulting in normal flexural slip. It is possible that the north-

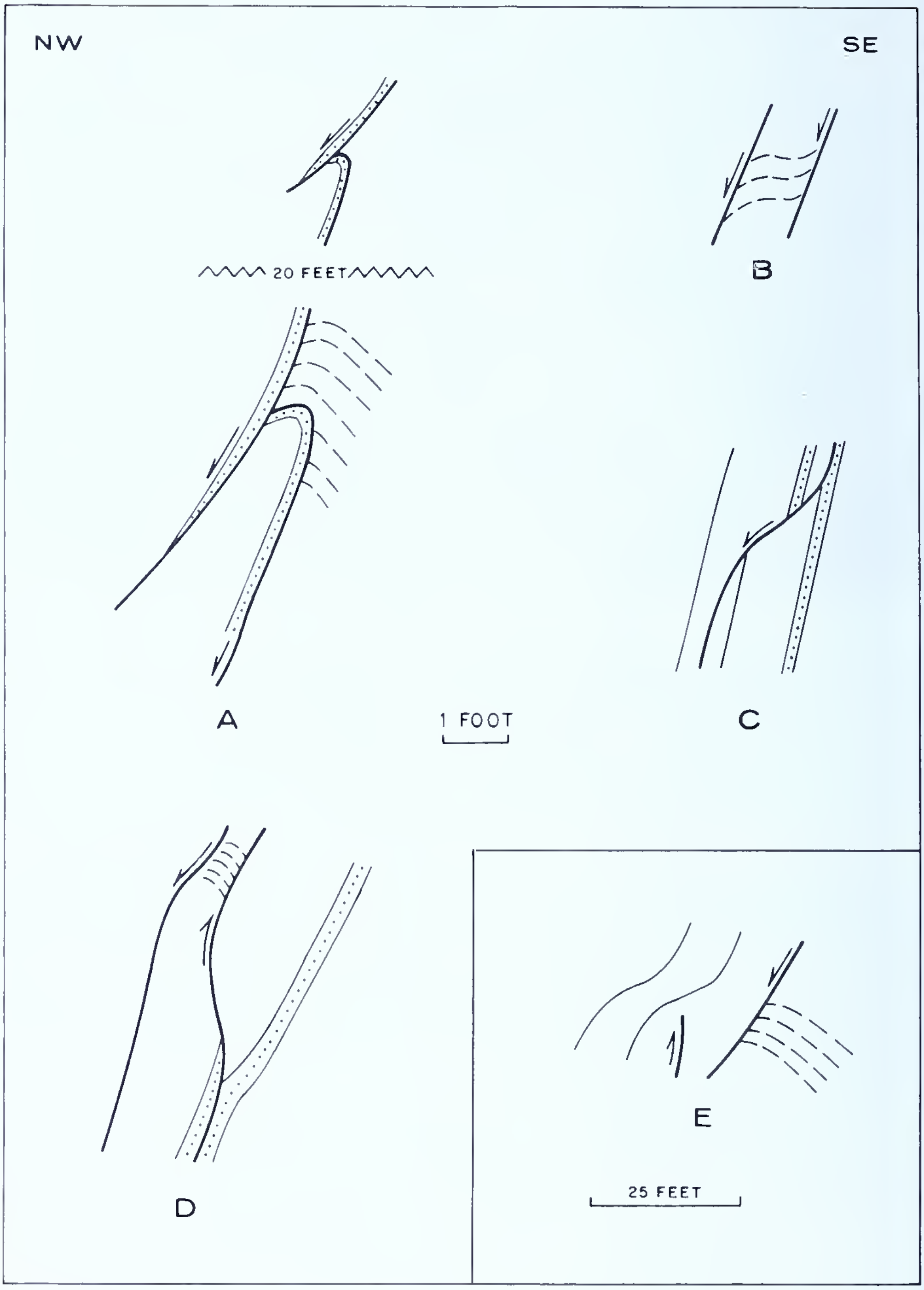

Figure 145. Diagrammatic sketches of wedges, bedding-slip surfaces, and dragged cleavage (traces of which are shown as dashed lines) in the Bloomsburg Red Beds at Lehigh Gap.

west-dipping thrusts, described previously, developed at this time to accommodate the northwest transport of the rocks.

Uplift and folding created the necessary northwest-dipping slope for sliding to develop. Sliding partly postdated cleavage development, as indicated by cleavage drag at Lehigh Gap. Locally, however, cleavage wrinkles bedding slickensides, showing that folding, cleavage development, and sliding were overlapping events. They probably developed during one continuous period of deformation, and their sequential order may have varied from place to place due to differences in local stress conditions.

## LOWER PART OF LITHOTECTONIC UNIT 3

The heterogeneous Upper Silurian to Middle Devonian rocks that make up lithotectonic unit 3 are complexly folded, so much so that early interpretations attributed many of the structural anomalies to faults (Chance, 1882a; Hill, 1887; Brown and Roedder, 1941). Faults are present locally, but Dyson (1956) first correctly interpreted the complex overturning in the area (Figure 146).

Most of the folds in lithotectonic unit 3 plunge southwestward. Overturned beds may pass abruptly into recumbent limbs or limbs rotated more than 180° (Figure 146), giving the impression that the fold collapsed under its own weight. Hence, the term "flap" (after Harrison and Falcon, 1936, as modified by Sitter, 1956, p. 274) may be applied to these folds. Cleavage in some flap folds has been rotated to the northwest along with the bedding, as reported along the Northeast Extension of the Pennsylvania Turnpike by Dyson (1956) and seen in the Buttermilk Falls Limestone in clay pits of the Universal Atlas Cement Company, 6 miles to the east in the Kunkletown quadrangle. This refolding may have been part of continuous deformation and occurred after the early folds became too tight to deform around the same axis. Movement was probably taken up by unsteady flow or slip in the encompassing ductile units (the Poxono Island and Marcellus Formations).

The folds in lithotectonic unit 3 appear to follow the form surface defined by lithotectonic unit 2 and not that which is defined by lithotectonic unit 4. This is supported by data from the New Jersey Zinc Company water well shown in cross section F-F′, which clearly shows that the folds in unit 3 follow the southeast overturned dip in the underlying Bloomsburg Red Beds and not the northwest dips in unit 4. It is upon this geometric relation between lithotectonic units 3 and 4 that the existence of the Sweet Arrow fault, to be discussed below, is based.

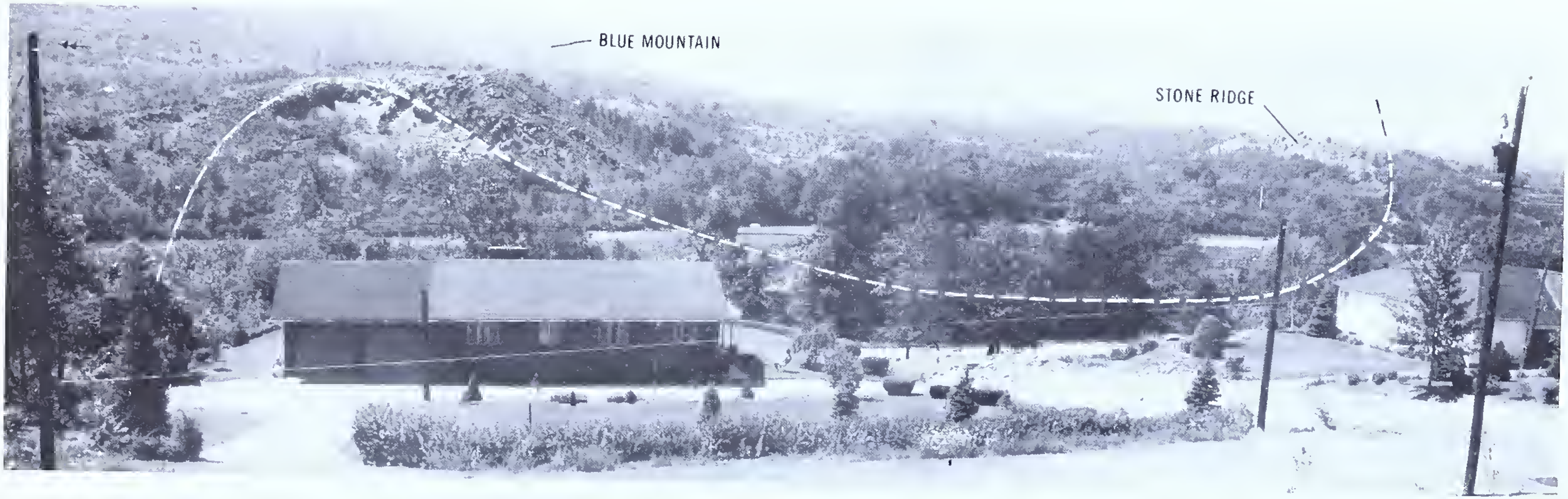

Figure 146. Recumbent fold in lithotectonic unit 3 in which some rocks have been rotated more than 180° to the northwest. View looking west across Lehigh River from Bowmanstown, Pennsylvania. The Palmerton Formation lies above the dashed line and younger rocks underlie it. Note the abrupt antiformal bend in this flap fold. The jagged crest of Stone Ridge is underlain by the upright steeply dipping Palmerton Formation to the right. Blue Mountain lies in the left background. The Northeast Extension of the Pennsylvania Turnpike is seen in the middle of the photograph. Dyson (1956) first correctly interpreted the structure of the area.

Cleavage is common in pelites and pelitic limestones in the lower part of lithotectonic unit 3. Cleavage may be concentrated in shaly fillings between mud-crack columns. The mud-crack polygons have been tectonically compressed (Figures 53 and 61).

## SMALL-SCALE STRUCTURES IN PRE-ORISKANY ROCKS

Linear and planar elements are numerous in rocks of lithotectonic units 1-3. Lineations include slickensides, axes of folds, intersections of bedding and cleavage, and intersections of cleavage and cleavage. Planar structures include joints, bedding, slaty cleavage, and slip cleavage.

### Slickensides

Bedding-plane slickensides are common in lithotectonic unit 2, less common in unit 1, and not seen in the lower part of unit 3 because of poor exposures. They are plotted on the geologic map (Plate 1) and fabric diagram (Figure 147). With few exceptions, as discussed under lithotectonic unit 2 above and in Figure 134, the overriding beds moved

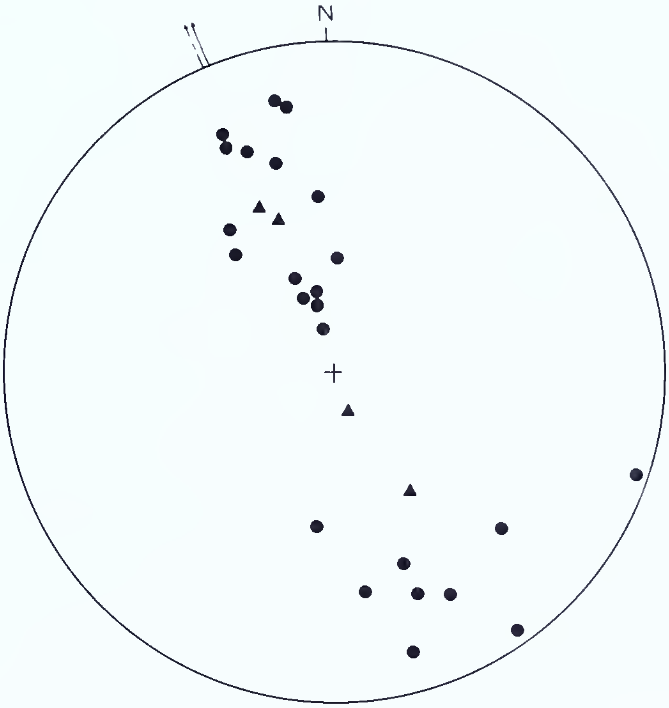

Figure 147. Equal-area projection (lower hemisphere) of bedding-plane slickensides in lithotectonic unit 1 (triangles) and lithotectonic unit 2 (circles) in the Lehighton and Palmerton quadrangles. Dashed arrow is mean trend in lithotectonic unit 1 (N67W); solid arrow is mean trend in lithotectonic unit 2 (N68W).

to the northwest. In the Martinsburg Formation at Lehigh Gap, slickensides become more abundant as the contact with the Shawangunk Formation and the Blue Mountain décollement is approached (Epstein and Epstein, 1969, p. 182). As shown in Figure 147, the mean trend of the slickensides in units 1 and 2 is N67-68W, suggesting a common stress direction for both.

## Intersections of Bedding and Cleavage

Measurements of the intersection of bedding and slaty cleavage were made directly where bedding and cleavage are well defined. Where bedding or cleavage are irregular, the intersections were computed with a stereographic net. These intersections approximate the trend of the axes of the folds in which they occur, but it can be shown geometrically that there is some variation from this trend if there is any fanning of the cleavage; that is, if the cleavage is not parallel to the axial surface of the fold in all parts of the fold. Cleavage in all rocks in the Lehighton and Palmerton quadrangles fans the folds to some extent, but, nevertheless, bedding-cleavage intersections give an approximation of axial trends. Figure 148 shows that the maxima of fabric diagrams of these lineations are similar for lithotectonic units 1 and 2. The same is true for the four lithotectonic units in the Stroudsburg area to the east (Epstein, 1971). However, the lineations in the Martinsburg Formation (lithotectonic unit 1) appear to have been rotated to the south as indicated by the girdles in Figure 148A and B. This apparent rotation may be due either to refolding of an earlier generation of folds and their associated cleavage (in which case the cleavage would also be rotated) or to imposition of cleavage during a later generation of folding on earlier formed folds (in which case the cleavage would not be rotated, but bedding would show signs of pre-cleavage folding). Figure 149 is a plot of bedding, cleavage, and intersections of bedding and cleavage selected from those localities that make up the anomalous girdle in Figure 148. By comparing the cleavage plot with that in Figure 154 and the bedding plot with that in Figure 153, it is clear that there has been no rotation of cleavage and that bedding defines an earlier generation of folds that plunge more southerly than the later generation of folds. The earlier folds are believed to have formed during the Taconic orogeny, and the later folds are believed to have formed during the Appalachian orogeny.

## Intersections of Cleavage and Cleavage

In many localities, slaty cleavage is wrinkled by slip cleavage, and the trend of the intersection of the two cleavages approximates the trends of the axes of the small wrinkles. The average trend of these intersections in lithotectonic unit 1 (maximum is 5°, S74W in Figure 150) is very similar to the trends of the earlier fold intersections shown in Figure 148. The trends of these intersections in lithotectonic unit 2 appear to be more southerly, but too few intersections were recorded for this to be significant. These lineations are probably present in lithotectonic unit 3, but none were seen because of poor exposures.

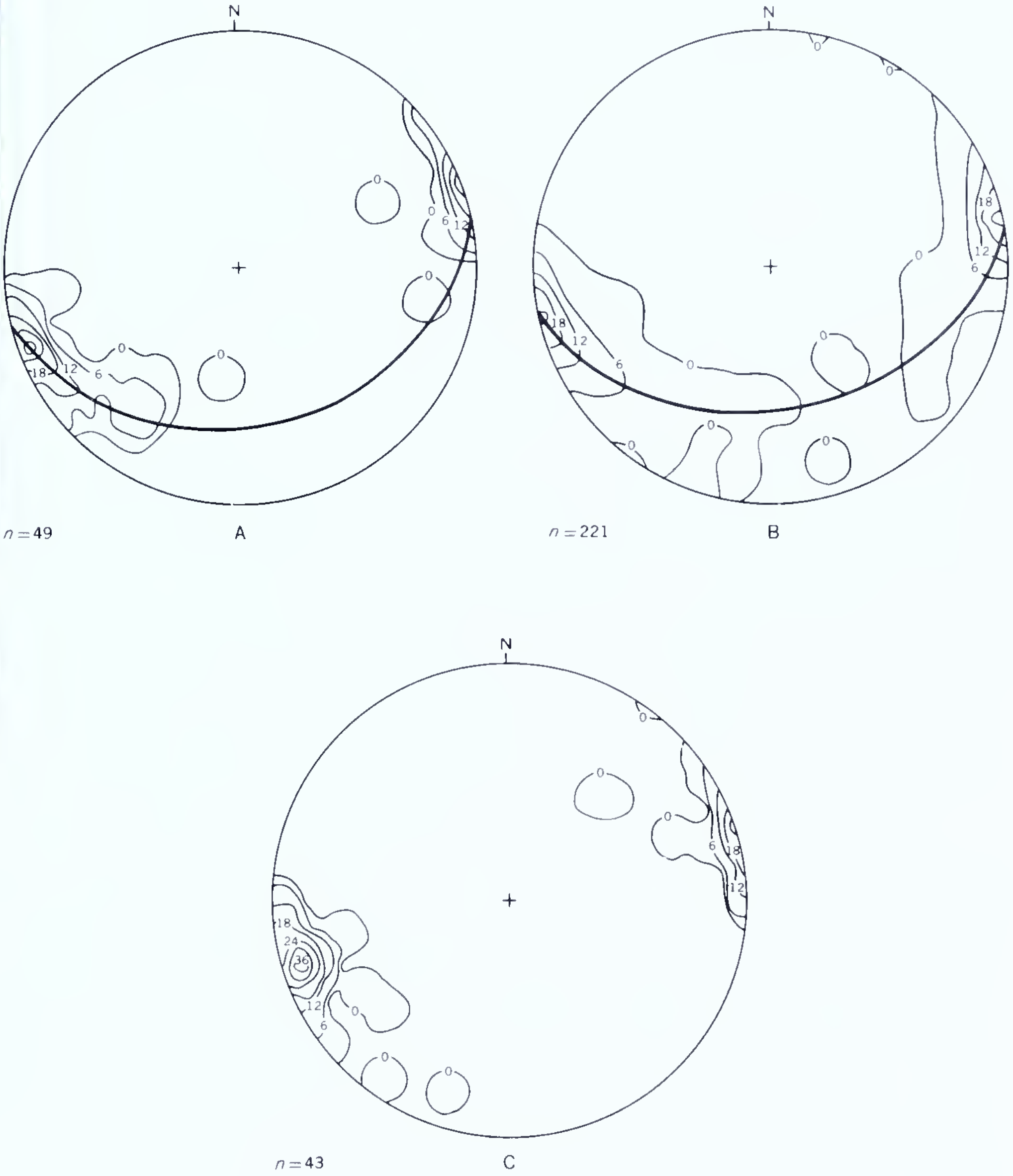

Figure 148. Equal-area projections (lower hemisphere) of intersections of bedding ($S_0$) and cleavage ($S_1$). Contour interval 6 percent per 1 percent area. A. Lithotectonic unit 1, Lehighton quadrangle, maximum at 5°, S71W. B. Lithotectonic unit 1, Palmerton quadrangle, maximum at 2°, S78W. C. Lithotectonic unit 2, Lehighton and Palmerton quadrangles, maximum at 6°, S73W.

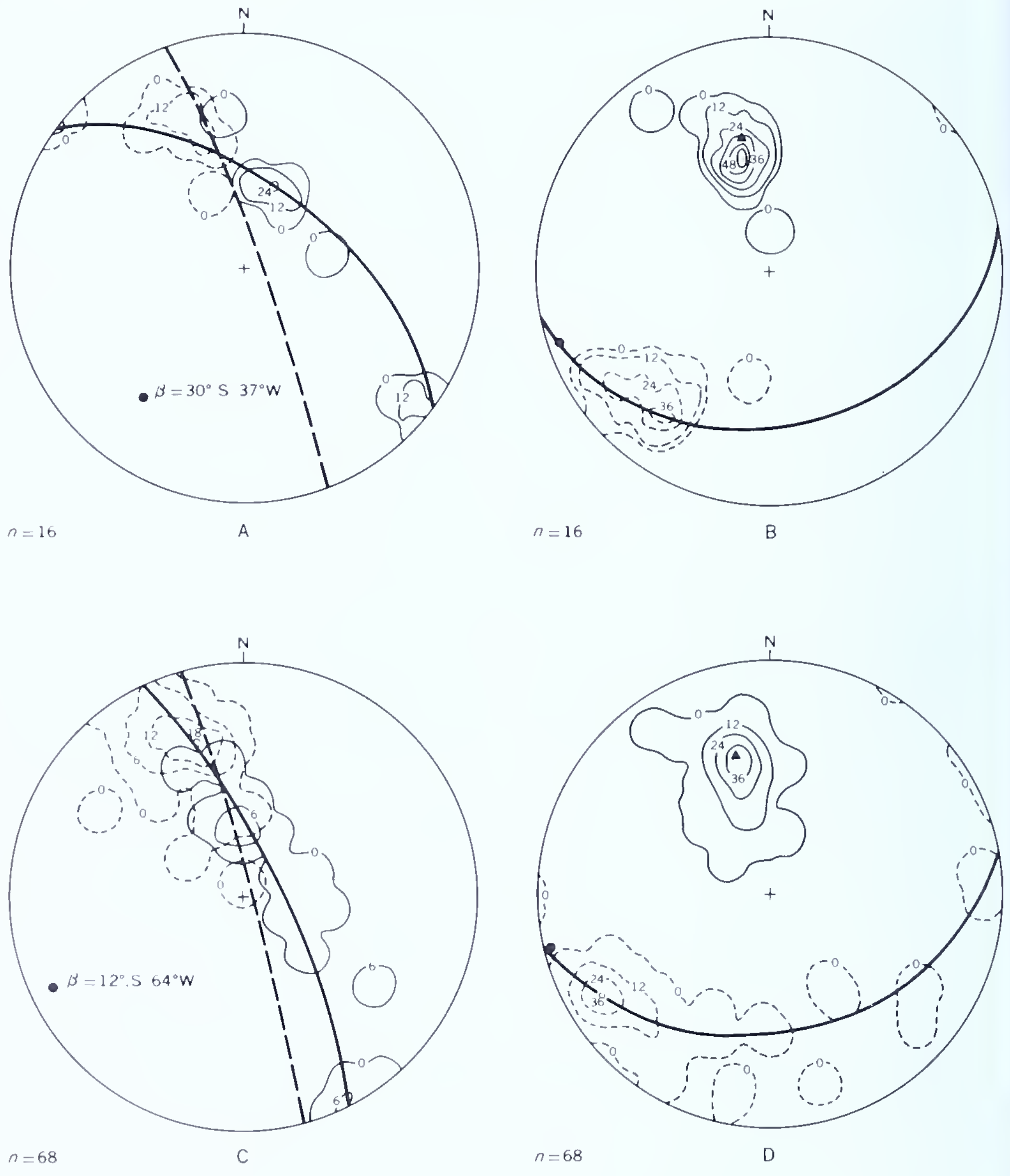

Figure 149. Equal-area projections (lower hemisphere) of intersections of bedding ($S_0$) and cleavage ($S_1$), poles to cleavage, and poles to bedding in the Martinsburg Formation (lithotectonic unit 1), selected from points that lie south of the concentration of points that surround the maxima in Figure 148A and B. Contour interval 12 percent per 1 percent area for A, B, and D, and 6 percent per 1 percent area for C. A. Bedding in the Lehighton quadrangle. Dashed contours are overturned beds, solid contours are upright beds; solid line is girdle defined by poles to bedding in this projection; dashed line is girdle from Figure 153A defined by poles to all measured bedding attitudes in the Lehighton quadrangle; solid circle is fold axis defined by girdle in this projection. B. Intersection of bedding and cleavage (dashed contours) (maximum at 25°, S37W) and cleavage (solid contours), Lehighton quadrangle. Solid line is girdle from Figure 148A defined by all bedding-cleavage intersections measured in the quadrangle; solid circle is maximum from Figure 148A; triangle is maximum of cleavage from Figure 154A. C. Bedding in the Palmerton quad-

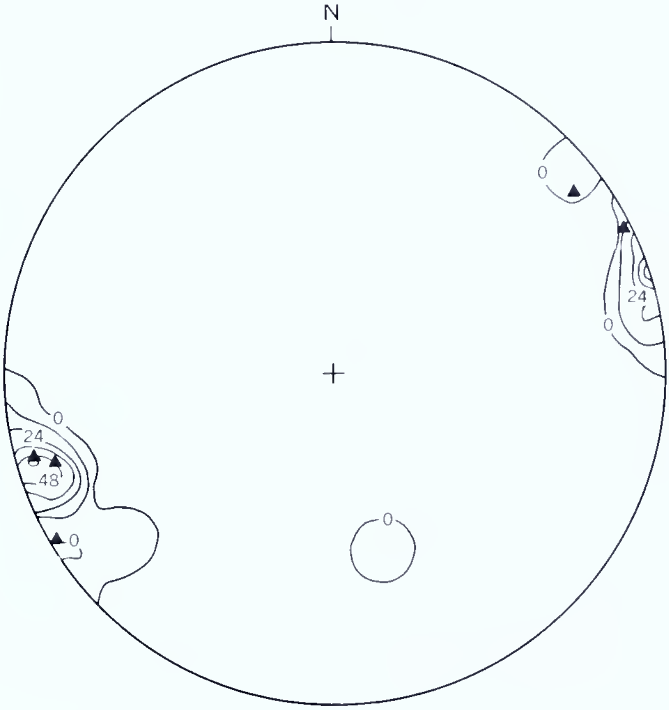

Figure 150. Equal-area projection (lower hemisphere) of intersections of slaty cleavage ($S_1$) and slip cleavage ($S_2$). Contours are intersections in the Martinsburg Formation (lithotectonic unit 1). Contour interval 12 percent per 1 percent area; n = 23; maximum at 5°, S74W. Solid triangles are intersections in lithotectonic unit 2.

## Joints

These planar features can be related to folds as cross, longitudinal, and oblique joints. They are smooth to rough, planar to slightly curved fractures generally several feet to tens of feet long. Calcite or quartz may line some joints. There generally has been no recognizable movement along joints, but in a few, displacement of a few inches has been noted. Fabric diagrams of joints in lithotectonic unit 1 through the lower part of unit 3 (Figures 151 and 152) show that cross (ac) joints are the most numerous. Their approximate strikes lie between N50-75W. Longitudinal (bc)

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rangle. Dashed contours are overturned beds, solid contours are upright beds; solid line is girdle defined by poles to bedding in this projection; dashed line is girdle from Figure 153B defined by poles to all measured bedding attitudes in the Palmerton quadrangle; solid circle is fold axis defined by girdle in this projection. D. Intersection of bedding and cleavage (dashed contours) (maximum at 16°, S58W) and cleavage (solid contours), Palmerton quadrangle. Solid line is girdle from Figure 148B defined by all bedding-cleavage intersections measured in the quadrangle; solid circle is maximum from Figure 148B; triangle is maximum of cleavage from Figure 154B.

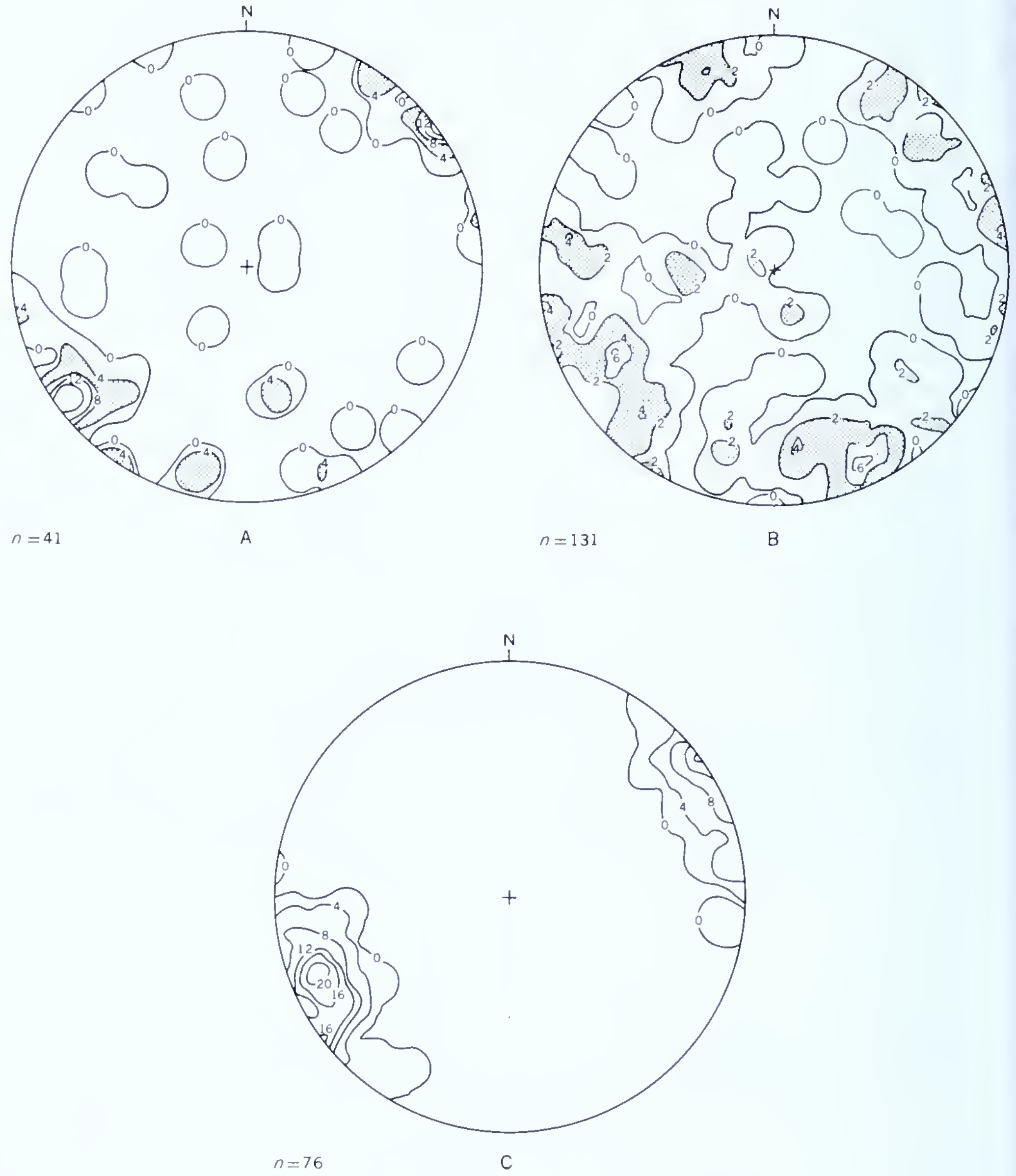


Figure 151. Equal-area projections (lower hemisphere) of poles to joints in the Martinsburg Formation (lithotectonic unit 1). A. Joints in the Lehighton quadrangle; contour interval 4 percent per 1 percent area; area between 4 and 8 percent stippled. B. Joints in the Palmerton quadrangle; contour interval 2 percent per 1 percent area; area between 2 and 4 percent stippled. C. Grain in the Palmerton quadrangle; contour interval 4 percent per 1 percent area.

joints trend about N20-30W in lithotectonic unit 2 (Figure 152A and B) and N15-25W in unit 1 (Figure 151A and B). A complex of oblique joints is present in the less competent rocks of unit 1. Few joints are exposed in the lower part of unit 3, but those that were measured indicate prominent cross joint sets and weaker longitudinal joint sets (Figure 152C).

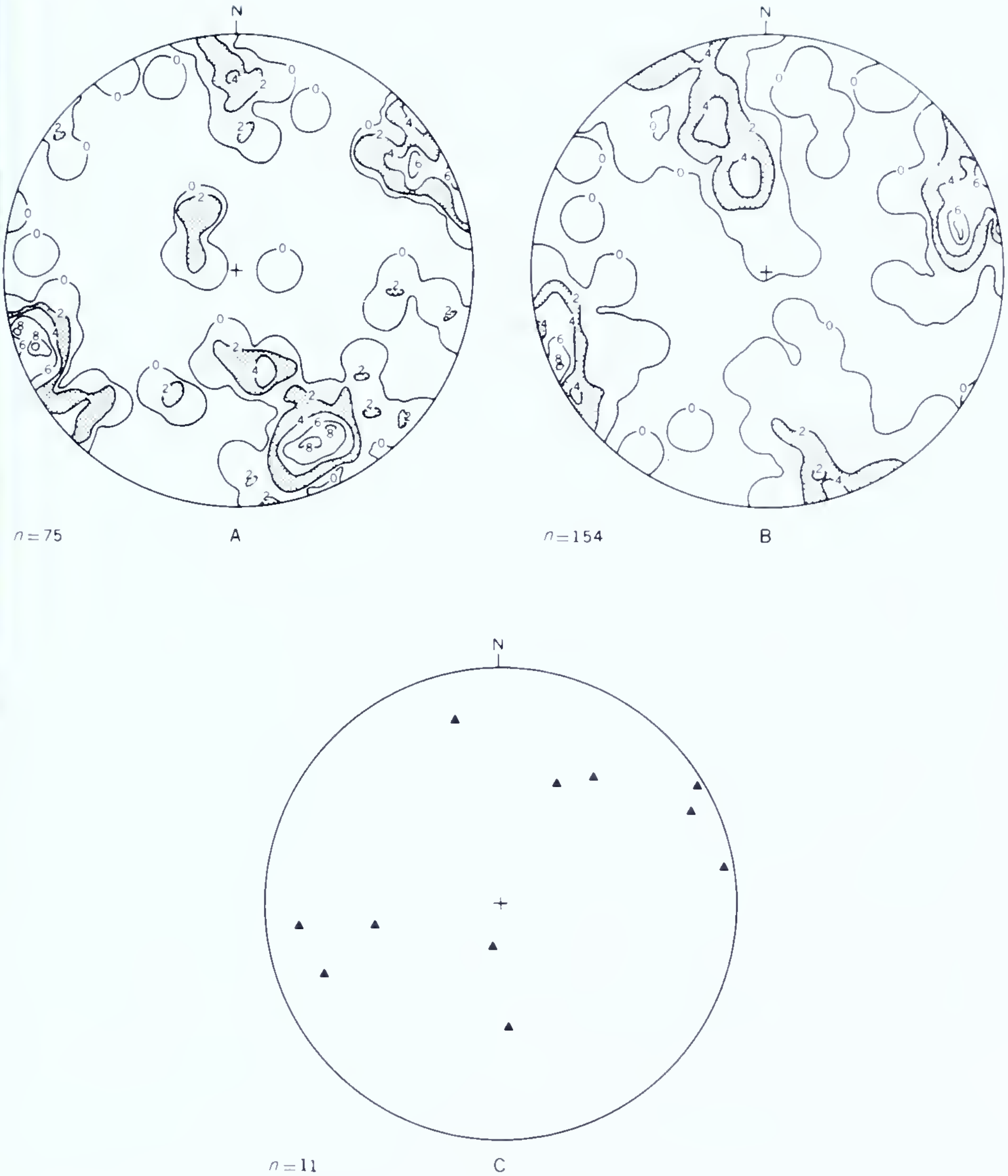


Figure 152. Equal-area projections (lower hemisphere) of poles to joints in lithotectonic units 2 and 3. A. Joints in lithotectonic unit 2, Lehighton quadrangle; contour interval 2 percent per 1 percent area; area between 2 and 4 percent stippled. B. Joints in lithotectonic unit 2, Palmerton quadrangle; contour interval 2 percent per 1 percent area; area between 2 and 4 percent stippled. C. Joints in the lower part of lithotectonic unit 3, Lehighton and Palmerton quadrangles.

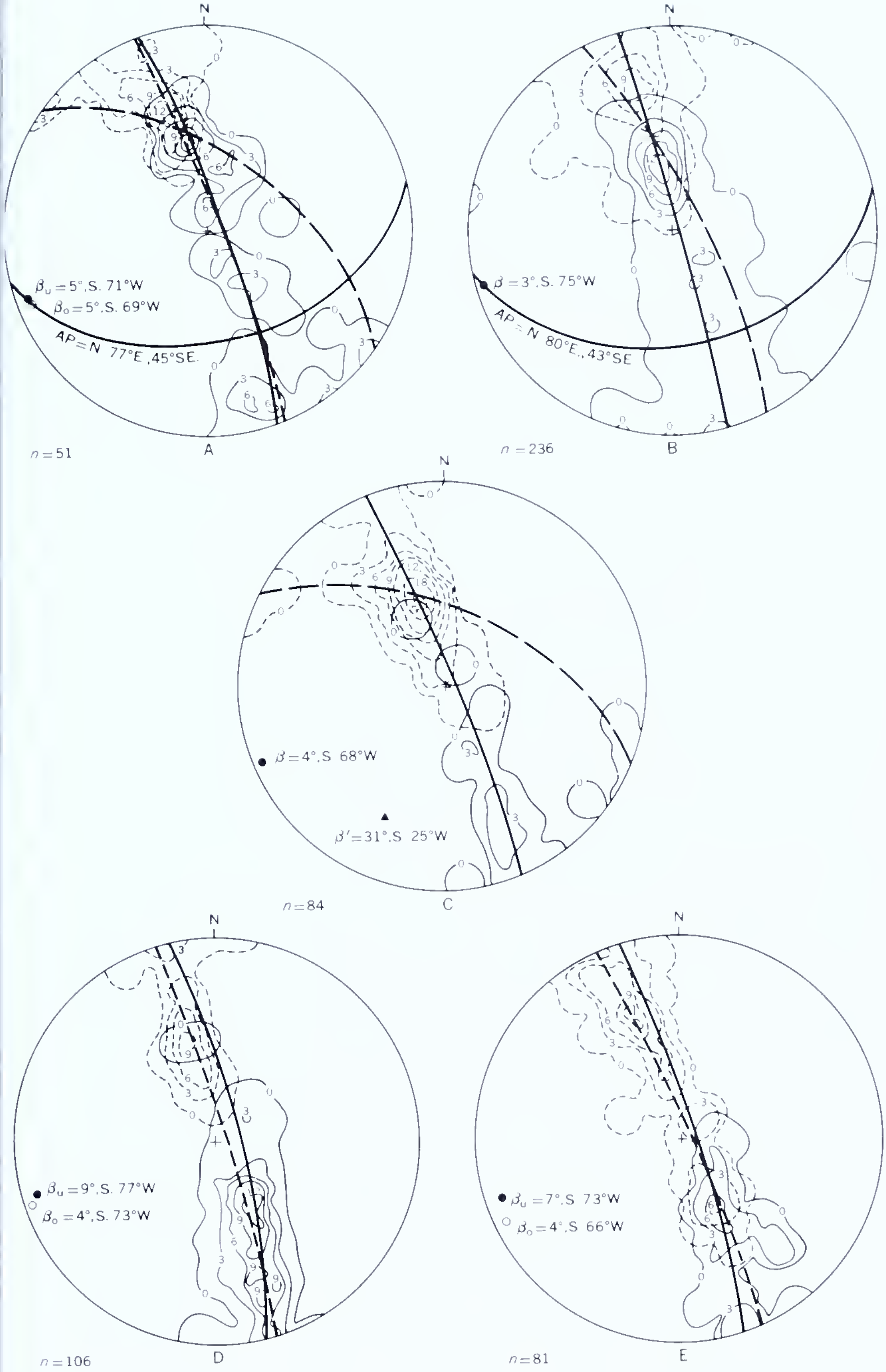
Figure 151C shows the grain in the slates of the Martinsburg Formation in the Palmerton quadrangle. Grain ("sculp" of quarrymen) is a direction of easy fracturing of slate approximately at right angles to cleavage and bedding, generally in the downdip direction of the slaty cleavage. The direction of splitting is believed to be controlled by the elongation of prismatic minerals, mainly quartz, in the direction of tectonic transport (the *a* direction) (for example, Dale and others, 1914; Behre, 1933; Broughton, 1946). Thus, the grain is generally curved and the dip is irregular, although the strike is consistent in a given outcrop.

Grain is important in removing slate from quarries. Fractures parallel to it form readily during blasting, and the sides of many quarries parallel the grain. The grain direction is determined in the field by hitting the rock flat on the cleavage and measuring the fracture produced. Dale and others (1914) noted that the grain is not perpendicular to the strike of cleavage in many slate districts, and this appears to be true in the Palmerton quadrangle where the grain's mean strike is N22W with a secondary peak at N37W. The mean cleavage strike is N78E (see Figure 154B). The main maximum for grain is thus off 10° from the perpendicular to the cleavage strike. This may be due to later rotation of the grain, but the mechanical significance of this is not clear.

## Bedding

Bedding is the primary planar structure and is used to define the geometry of folds. The characteristics of the folds have been described under the lithotectonic units, and their geometries may be further studied by plotting bedding on equal-area nets (Figure 153). The girdles defined by the poles to bedding indicate the mean plunge of the folds ($\beta$). The plunges are similar in all units and average 3°-9°, S66-77W. These plunges are similar to the maxima for intersections of bedding and cleavage

Figure 153. Equal-area projections (lower hemisphere) of poles to bedding ($S_0$). Contour interval 3 percent per 1 percent area. Solid contours are upright beds, dashed contours are overturned beds (northwest-dipping overturned beds in E have been rotated more than 180°). Solid lines are girdles defined by poles to bedding in B and C, and the solid circles are fold axes ($\beta$). In A, D, and E, upright and overturned beds define different girdles and the solid lines are girdles for upright beds (solid circles show the fold axes, $\beta_u$), and short-dashed lines are girdles for overturned beds (open circles show the fold axes, $\beta_0$). Long-dashed line in A is the girdle for earlier folds in the Martinsburg Formation shown in Figure 149A, in B it is the girdle for earlier folds in the Martinsburg Formation shown in Figure 149C, and in C it is the girdle for later folds in the Shawangunk Formation and Bloomsburg Red Beds (triangle shows the later fold axes, $\beta'$). Solid lines AP in A and B are attitudes of axial planes of folds derived from their average pole that lies midway between the overturned and upright limb maxima. A. Lithotectonic unit 1, Lehighton quadrangle. B. Lithotectonic unit 1, Palmerton quadrangle. C. Lithotectonic unit 2, Lehighton quadrangle. D. Lithotectonic unit 2, Palmerton quadrangle. E. Lithotectonic unit 3, Lehighton and Palmerton quadrangles (includes data from upper part of unit from W. D. Sevon).


N
$\beta_u = 5°$, S. 71°W
$\beta_o = 5°$, S. 69°W
AP = N 77°E, 45°SE.
$n = 51$
A
N
$\beta = 3°$, S. 75°W
AP = N 80°E., 43°SE
$n = 236$
B
N
$\beta = 4°$, S 68°W
$\beta' = 31°$, S 25°W
$n = 84$
C
N
$\beta_u = 9°$, S. 77°W
$\beta_o = 4°$, S. 73°W
$n = 106$
D
N
$\beta_u = 7°$, S 73°W
$\beta_o = 4°$, S 66°W
$n = 81$
E

shown in Figure 148, suggesting that the cleavage is an axial-plane foliation and symmetrically fans the folds. The folds are not purely cylindrical because in some units upright beds and overturned beds define different girdles (Figure 153A, D, and E). This is taken to indicate rotation of the overturned limbs in a slightly different direction than the original stress direction that initially formed the folds (for example, see Figures 138 and 139).

The tightness of the folds may be judged by the angle between the limb maxima of upright and overturned beds. This is statistically possible for lithotectonic unit 1 where many parts of many folds were sampled. In the Lehighton quadrangle, the angular spread of the limbs is 16°, and in the Palmerton quadrangle it is 38° and shows that the folds are fairly tight. However, the same analysis is not possible for lithotectonic unit 2 in the Lehighton quadrangle, because most of the exposed beds are in overturned limbs of the folds, and a meaningful maxima for upright beds was not obtained (Figure 153C), nor is it possible for lithotectonic unit 2 in the Palmerton quadrangle (Figure 153D) because most of the beds exposed in that unit are in the trough and upright limb of an overturned syncline (see cross section E-E′, Plate 1). Likewise, the tightness of the folds cannot be determined for lithotectonic unit 3 from Figure 153E, because of few exposures of rocks in that unit and because of complexly warped axial planes.

Where statistically meaningful maxima of fold limbs are obtained, the average trend of the axial planes of the folds can be determined by plotting the great circle whose pole lies midway between the limb maxima and which includes the fold axes. The average attitudes of axial planes for lithotectonic unit 1 (N77-80E, 43-45SE) are shown in Figure 153A and B. These attitudes are in harmony with those shown in the geologic map and cross sections (Plate 1). Figure 153D suggests that the axial planes in lithotectonic unit 2 are nearly upright, but as mentioned above, most of the plotted beds are those exposed in the upright beds of an incompletely exposed overturned fold at Lehigh Gap.

Most of the folds shown in the fabric diagrams of Figure 153 are Appalachian in age, but the girdles of bedding in folds in the Martinsburg Formation that are believed to be Taconic in age are shown in A and B. These girdles are also derived in Figure 149 and discussed under intersections of bedding and cleavage above.

In Figure 153C, there is a similar subsidiary bedding girdle shown in lithotectonic unit 2, but this folding is believed to be a later Appalachian event, because the intersections of bedding and cleavage apparently have not been rotated as they have been in lithotectonic unit 1, as discussed earlier. This later rotation of bedding is shown near Little Gap and is discussed under lithotectonic unit 2. Thus, the history of deformation for rocks in the Lehighton and Palmerton quadrangles is complicated, and at least three periods of folding are identified.

## Cleavage

Most pelitic rocks in lithotectonic units 1-3 have a prominent secondary foliation, or slaty cleavage (see Figures 2-4, 5, 6, 18, 24, 35, 41, 42, 44B, 51-53, 58, 60, 67, 134-141, 144, 145). A second slip cleavage is locally developed in all units (see Figures 31, 134, 139, for example). Measured attitudes of these cleavages are shown in Figure 154. Preliminary discussions of cleavage in these rocks in eastern Pennsylvania are given in Epstein and Epstein (1967, 1969), Epstein (1971, 1973), and U.S. Geological Survey (1969b, 1971). Space does not permit a complete discussion of ongoing studies of this planar structure; the following is a terse summary of conclusions to date.

Microscopic and field relations of the cleaved rocks suggest that slaty cleavage forms by laminar flow and intrusion of pelitic material along anastomosing folia accompanied by mechanical reorientation of platy and elongate minerals and by new mineral growth. Elongation of quartz and its removal from cleavage folia results from corrosion by pressure solution perpendicular to the cleavage direction. The cleavage folia are separated by more quartz-rich areas in which reorientation of platy minerals and dimensional alignment of prismatic minerals has not taken place, or is not as well developed. Numerous lines of evidence point to the conclusion that cleavage developed after the rock was indurated. Plasticity increased during increased tectonism and the mobility (intrusion of pelitic and sandy material along cleavage planes) may have been aided by silica derived from pressure solution and derived either from connate water squeezed out of the rocks during tectonic compaction or by the release of water from hydrous minerals during continued deformation. New growth of quartz, chlorite, muscovite, calcite, and probably albite in most rocks suggests formation of cleavage at and just below the limits of low-grade metamorphism (quartz-muscovite-albite-chlorite subfacies of the greenschist facies).

Slip cleavage crenulates earlier foliations. Transposition of minerals into the new cleavage plane is common, and in this respect it is similar to slaty cleavage. It is also similar to slaty cleavage in that new minerals may grow parallel to the cleavage direction.

These findings disagree with several aspects of the concept of the origin of cleavage by tectonic dewatering under nonmetamorphic conditions developed for the Delaware Water Gap area by Maxwell (1962), although they do not rule out the possibility that cleavage may have been initiated by the dewatering mechanism.

At Lehigh Gap cleavage appears to die out in the Martinsburg Forma-

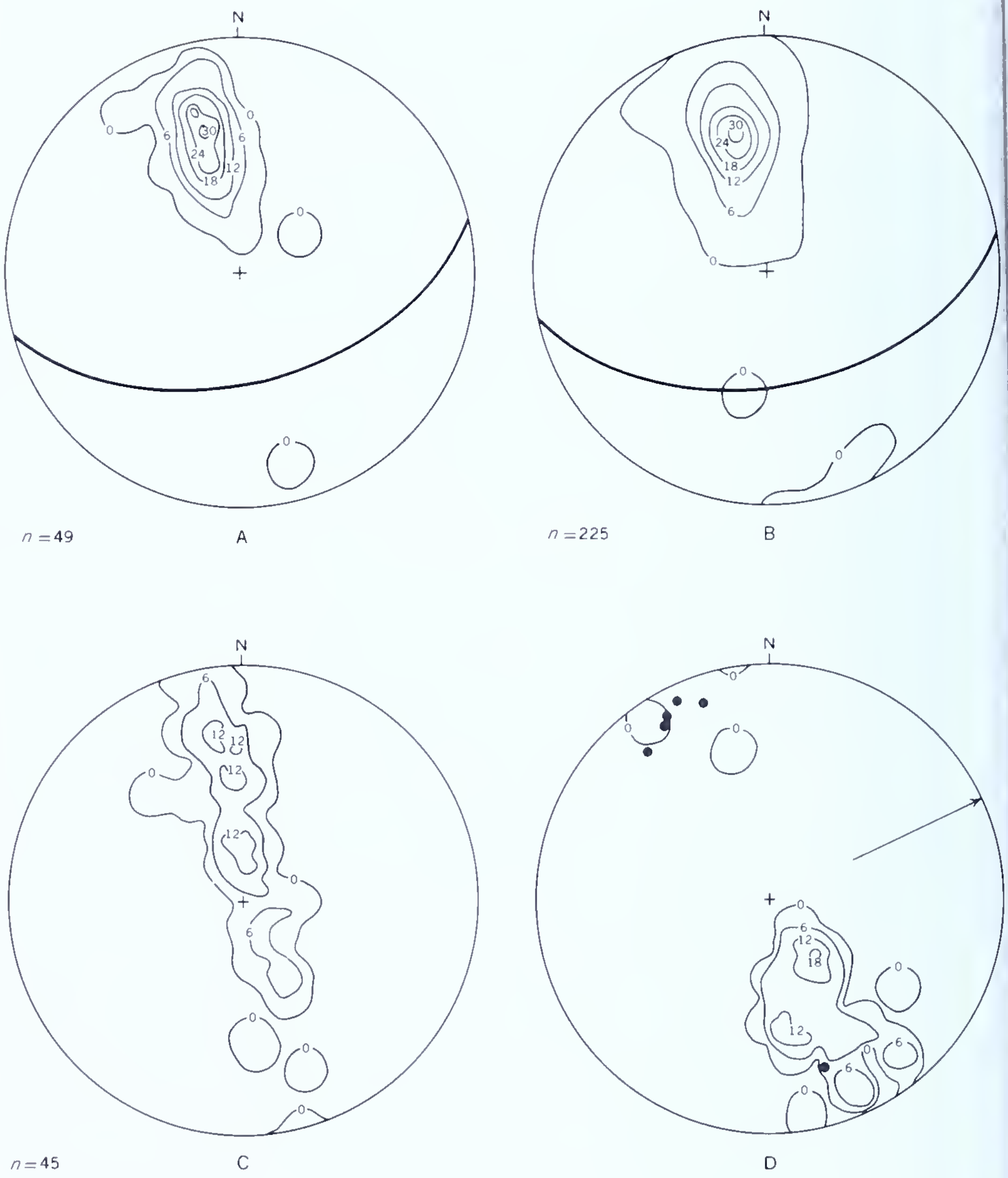


Figure 154. Equal-area projections (lower hemisphere) of poles to cleavage, $S_1$ (A, B, and C), and to slip cleavage, $S_2$ (D). Contour interval 6 percent per 1 percent area. Heavy lines in A and B are mean attitudes of cleavage derived from the maximum. A. Cleavage in lithotectonic unit 1, Lehighton quadrangle, maximum at N76E, 52SE. B. Cleavage in lithotectonic unit 1, Palmerton quadrangle, maximum at N78E, 50SE. C. Cleavage in lithotectonic unit 2, Lehighton and Palmerton quadrangles (most northwest-dipping cleavage is in the Shawangunk Formation). D. Slip cleavage in lithotectonic unit 1 (contoured, n = 27) and in lithotectonic unit 2 (solid circles), Lehighton and Palmerton quadrangles (arrow shows mean strike of all slip cleavages).

tion as the contact with the Shawangunk Formation is approached; this was described by Epstein and Epstein (1969, p. 182). However, microscopic examination shows that the regional southeast-dipping cleavage is present in many of the beds near the contact, although it is generally poorly developed. In addition, there is a near-vertical slip cleavage within a few feet of the contact (Figure 134). In the Martinsburg at this locality there is a second slaty cleavage which dips less steeply than bedding and which has sandstone dikes subparallel to it. This slaty cleavage parallels a similar cleavage in pelites in the overlying Shawangunk. The dikes are interpreted to have been intruded parallel to cleavage very early during cleavage formation and were later rotated out of parallelism.

## UPPER PART OF LITHOTECTONIC UNIT 3

Stony, Stone, and Chestnut Ridges are part of a complex series of southwest-plunging upright and overturned third-order folds (Nickelsen, 1963, p. 16) in rocks of the Ridgeley, Schoharie-Esopus, and Palmerton Formations. The complexity of the folds is indicated by the outcrop pattern in Plate 1, in the block diagrams in Figure 157, and in Figures 155, 156, and 158. The largest and best exposed fold occurs between Palmerton and Bowmanstown and was first properly interpreted by Dyson (1956) (see Figure 146).

The folds plunge to the southwest and have an average axial trend of about S67W (range S34-85W), an average wavelength of 2,500 feet or less, and an average amplitude of 1,500 feet or less.

Rocks in the Stony Ridge complex show little evidence of the intensity of the folding. Joints and fractures are numerous in the Palmerton Formation (see section on small-scale structures), generally have vein fillings of quartz, or less commonly, hematite, and may have slickensided surfaces. However, bedding is virtually nonexistent in the Palmerton, and no evidence of movement along bedding-parallel surfaces has been observed. Although the Schoharie-Esopus Formation has numerous joint surfaces also, very few vein fillings or slickensides were noted. Of particular interest is the apparent lack of any distortion or deformation of the fossils present in the upper half of the Schoharie-Esopus or the many sedimentary structures in the lower half of the unit. The same is true of the Ridgeley Formation which is typified by bedding-plane alignments of apparently undistorted brachiopod valve molds.

Several faults occur in lithotectonic unit 3. Offset beds southwest of Germans indicate a fault of unknown attitude and magnitude. Several low-angle north-dipping thrust faults are exposed in a quarry north of Palmerton and are shown in Figure 155. The two larger faults strike

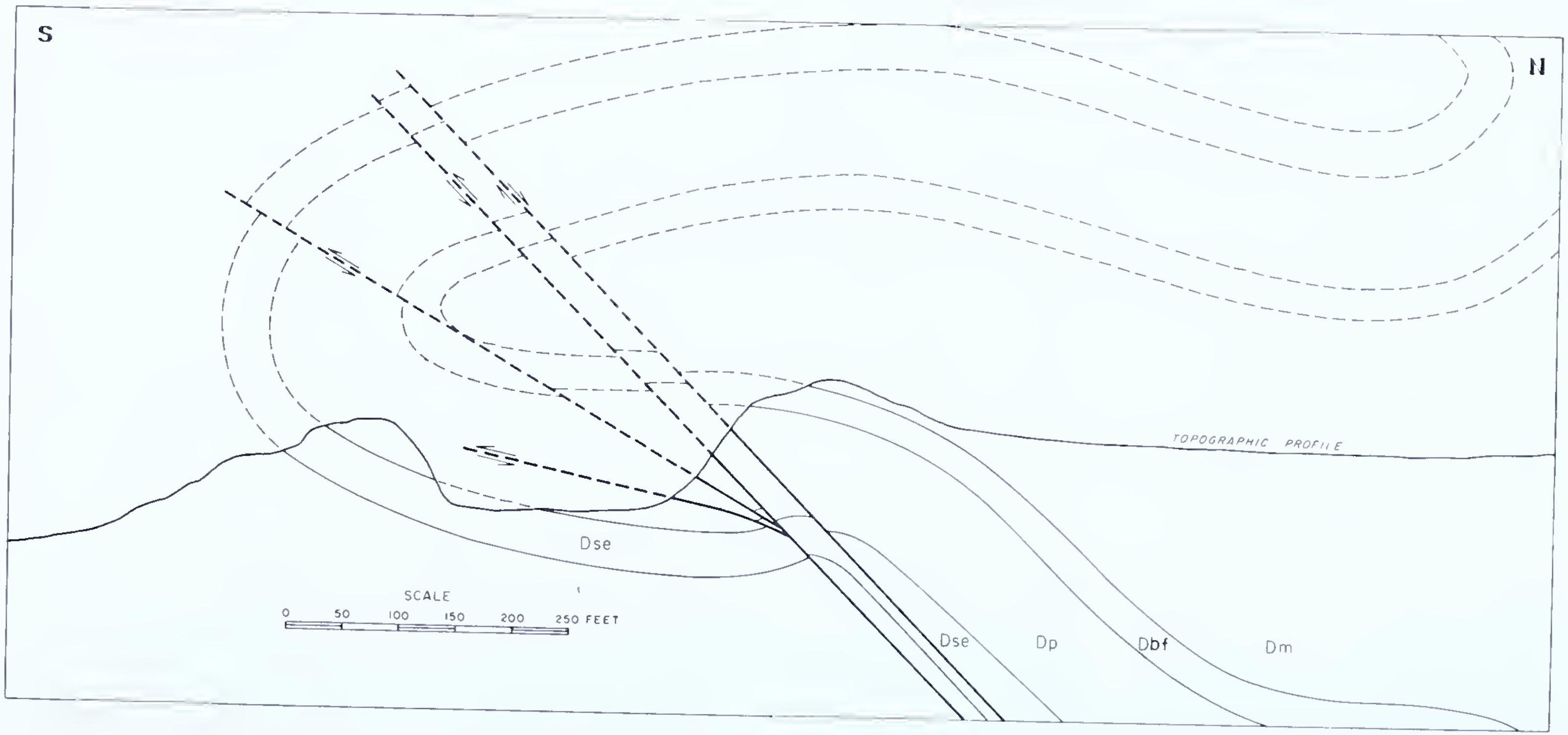


Figure 155. Cross section of Stony Ridge structure in the easternmost quarry of the Alliance Sand Company, Palmerton. Quarry located immediately north of Palmerton at 40°48′12″N/75°37′48″W. Modified from an unpublished original by J. F. Wietrzychowski. Dse, Schoharie-Esopus Formation; Dp, Palmerton Formation; Dbf, Buttermilk Falls Limestone; Dm, Marcellus Formation.

N78E and dip 59N (Figure 155 shows apparent dip). Displacement is estimated to be 6 to 10 feet. A steep, south-dipping reverse fault of unknown magnitude intersects an overturned fold in the Butz quarry north of Palmerton (Figure 156). High-angle faults are inferred from repetition of the Palmerton Formation at Little Gap; an interpretation of the faulting there is presented in Figure 158.

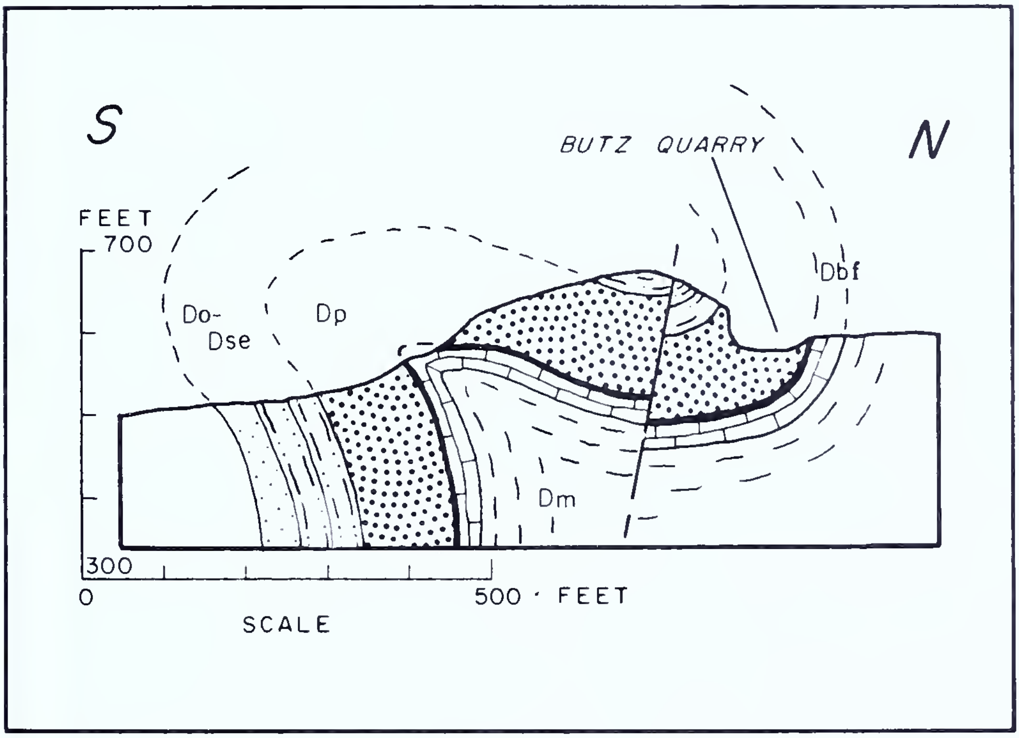


Figure 156. Cross section of Stony Ridge structure at the Butz quarry, Palmerton. Unpublished original by J. F. Wietrzychowski. Symbols same as symbols on Plate 1, except Dm (Marcellus Formation) and Dbf (Buttermilk Falls Limestone).

## LITHOTECTONIC UNIT 4

Three asymmetrical folds are the dominant structural elements in lithotectonic unit 4. These are the Weir Mountain syncline, the Lehighton anticline, and the Mount Pisgah syncline. They trend about N70E across the mapped area and extend beyond the boundaries of the quadrangle (Figure 159).

The Weir Mountain syncline (Plate 1, Figure 159 and cross section A-A′) is a major, broad, westward-plunging fold which closes near Saylorsburg (about 10 miles northeast of the mapped area) and opens and loses definition in the region of the Little Schuylkill River (about 14 miles southwest of the mapped area) (Figure 159). The Weir Mountain syncline is divided into two parts by a small anticline which forms a structural platform to the southwest of Dry Tavern (south of Lehigh-

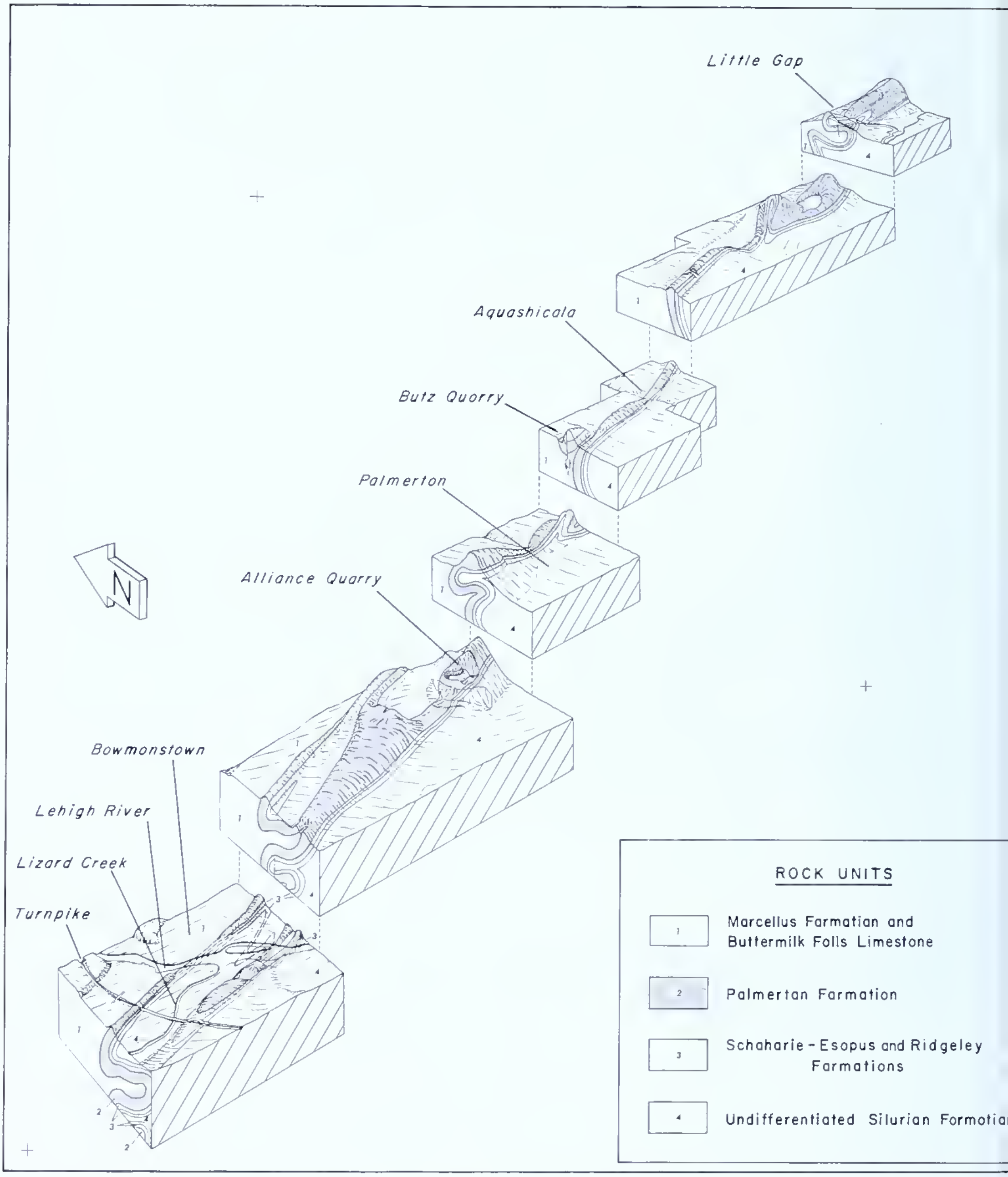


Figure 157. Structural complexity of folding in Stony Ridge between the Lehigh River and Little Gap. Modified from an unpublished original by J. F. Wietrzychowski.

ton). Between Dry Tavern and Saylorsburg the Weir Mountain is a doubly plunging, canoe-shaped, broad synclinorium which attains its maximum width (5 miles) near the northeast corner of the mapped area.

Dips on the south flank of this syncline are steep, average about 58° north (range 14°-90°), and are locally overturned as much as 30° south. Dips on the north flank of the fold have an average dip of 33° south

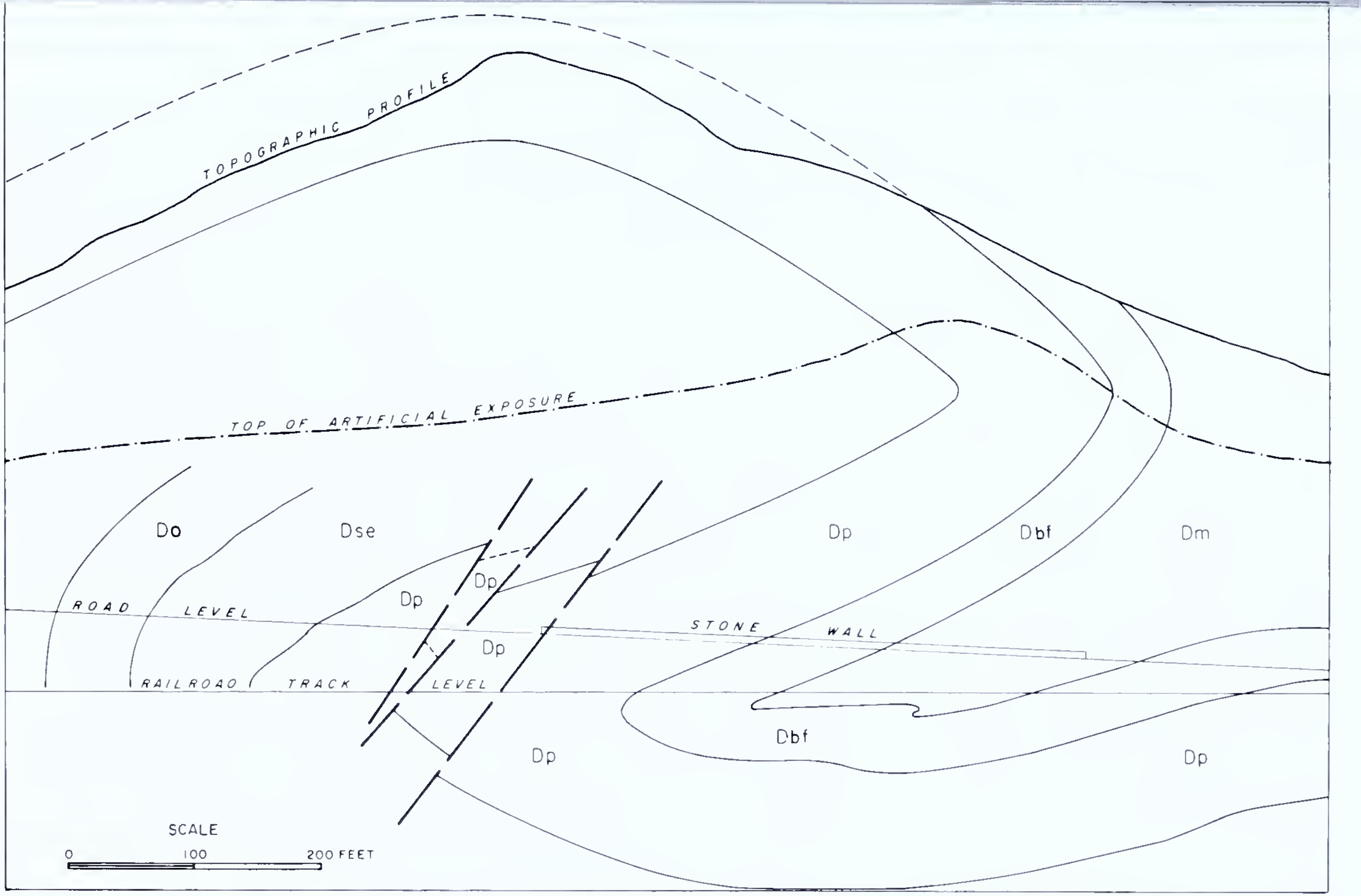


Figure 158. Cross section of Stony Ridge structure at Little Gap. General line of the cross section is parallel to the road on the west side of Buckwha Creek. Modified from an unpublished original by J. F. Wietrzychowski. Symbols same as symbols on Plate 1 except Dm (Marcellus Formation) and Dbf (Buttermilk Falls Limestone).

(range 21°-70°). Smaller folds (presumably symmetrical) occur within the syncline, but lack of outcrop prevents delineation of these folds except along the Lehigh River north of Bowmanstown (cross section A-A′).

Some westward-plunging and asymmetrical flexural-slip folds with axes inclined to the south occur on the south flank of the Weir Mountain syncline (Wietrzychowski, 1964). These folds have a steep north-dipping flank and a gentle south-dipping flank. Bedding-plane slickensides associated with these folds indicate movement normal to the fold axis.

The crest of the Lehighton anticline underlies the topographic low of the Mahoning and Pohopoco Creek valleys and brings rocks of the Marcellus Formation to the surface in the area of Lehighton. It is a westward-plunging fold which closes near South Tamaqua (11 miles southwest of the mapped area) and opens toward Stroudsburg (18 miles northeast of the mapped area) (Figure 159). The axis of the fold parallels that of the Weir Mountain syncline. The anticline has a gently dipping south flank (see above) and a steeply dipping north flank. The north flank has an average dip of 83° north (range 40°-90°) and is locally overturned as much as 25° south.

Asymmetric flexural-slip folds with axes inclined to the south occur near the top of the Beaverdam Run Member of the Catskill Formation. One such fold is exposed on the southwest side of the road at the junction of U.S. Route 209 and a secondary road in the Beaverdam Run valley north of Jamestown. Another fold is exposed on the Northeast Extension of the Pennsylvania Turnpike at Walcksville.

Numerous small third- and fourth-order folds (Nickelsen, 1963, p. 16) occur north of the main axis of the Lehighton anticline in the north-central part of the mapped area. Similar folds have also been mapped farther northeast in the adjacent Pohopoco Mountain quadrangle (Sevon, in press) and probably occur farther southwest in the area but have not been detected because of the scarcity of outcrop. Some of these folds are well displayed along the north side of the emergency spillway of the Beltzville Dam. Determination of bed top by primary features is usually not possible, and cleavage relations have been utilized almost exclusively as an indication of overturning. Although some fold axes have been extended laterally for several miles, this continuity is not certain due to the absence of outcrops between stream valleys. The folds are generally small, having wavelengths from a few tens of feet to a few hundreds of feet.

The Mount Pisgah syncline "is the eastern extension of the Panther Valley syncline of the Southern anthracite field" (Klemic and others, 1963, p. 58). The axis of this syncline is parallel to the axes of the two other major folds discussed above and extends northeastward to Call

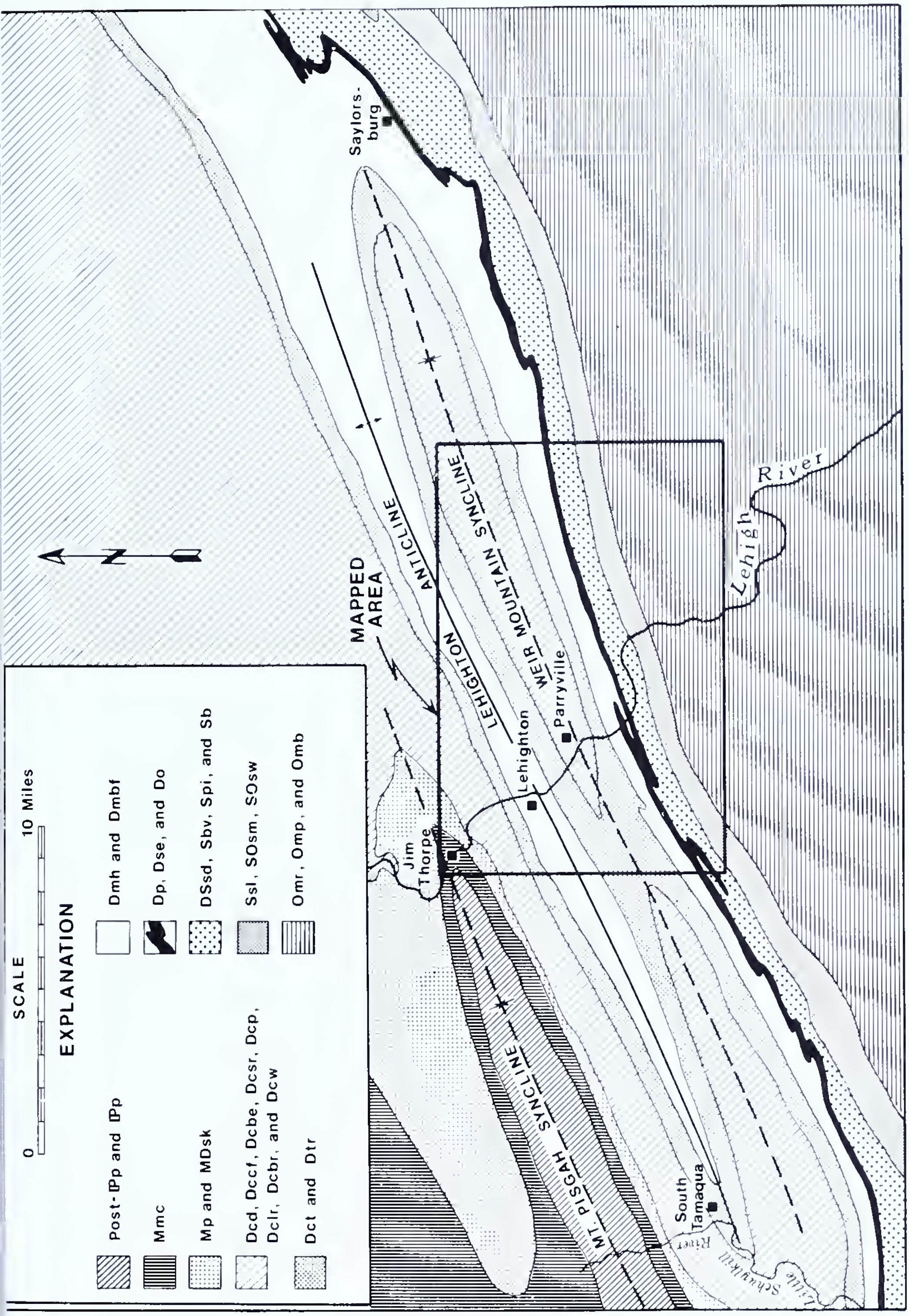


Figure 159. Relation of the mapped area to regional geology and structure. Modified from Gray and others (1960).

Mountain. Klemic and others (1963, p. 58) calculated a plunge of about 12° to the southwest for this syncline.

The Mount Pisgah syncline is asymmetrical with a steeply dipping south limb which is in places overturned. To the northeast of the mapped area, this steeply dipping south limb has gentler north dips and lacks overturning. The north limb of the syncline has gentle south dips which generally do not exceed 40°. No secondary folds on the limbs of this syncline have been observed.

Several faults have been mapped in lithotectonic unit 4. Some are minor, but others are of regional importance, including the Sweet Arrow fault which is discussed in the following section.

Three faults of regional importance have been extended into the area on the basis of information from mapping being done to the west in the Nesquehoning quadrangle by G. H. Wood, Jr., U.S. Geological Survey. The actual existence of these faults is not presently demonstrable in the mapped area, but their regional persistence to the west and the tracing of these faults to the western boundary of the mapped area (G. H. Wood, Jr., oral commun., 1971) implies their existence in the mapped area.

The southernmost of these faults is the Beaverrun fault, which lies along the contact between the Beaverdam Run and Long Run Members of the Catskill Formation. West of the mapped area, stratigraphic thickening and thinning of the Long Run and cutting out of traceable units within the formation indicate the existence of the fault (G. H. Wood, Jr., oral commun., 1971). Similar situations have not been demonstrated in the mapped area, and the fault is ended at the Lehigh River. A small asymmetric flexural-slip fold which may be associated with the fault is exposed at the southwest corner of the junction of a secondary road in Beaverdam Run valley and U.S. Route 209.

The next two faults are the Mauchono fault and the Pottchunk fault. Both are concealed in the mapped area. The Mauchono fault occurs near the base of the Mauch Chunk Formation, and the Pottchunk fault occurs within the Mauch Chunk-Pottsville transition zone in areas to the west. Both of these faults have been folded and are discussed by Wood and others (1969, p. 95-100).

A small bedding-plane fault is exposed along Mahoning Creek on the north flank of the Weir Mountain syncline south of Lehighton. It strikes N77E and dips 22S. Some distortion of the underlying beds has occurred. Slickensides trend N22W, dip 21S, and indicate movement of the overlying beds away from the center of the syncline. The fault is probably a large bedding-plane slip which has distorted the underlying beds.

Another small fault occurs in the Packerton Member of the Catskill Formation north of Packerton along the north-south part of a road which intersects U.S. Route 209 immediately north of the Packerton outcrop belt. This fault is nearly horizontal and has a displacement of 22 inches, the upper plate having apparently moved northward relative to the lower plate. The northern end of the fault is lost in cover, and there is no displacement at the southern end of the fault, although the fracture is present. This fault may be the base of a large slump block which has initiated movement along a well-developed fracture zone. The fault zone is deeply recessed by weathering and appears to consist of numerous broken pieces of sandstone and siltstone.

Numerous bedding-plane slips and wedge faults in lithotectonic unit 4 occur in exposures along the east bank of the Lehigh River along Pa. Route 248 north of Bowmanstown and are illustrated in Figure 160.

The following discussion of bedding-plane slip and wedge faults is taken from Glaeser (1967, p. 97):

> Bedding-plane slip is best developed between planes of units 16-18. Gouge, slickensides, leached color and cleavage drag are all evidence of faulting. In the north limb of the syncline, this fault follows the plane defined by the top of unit 17. Nature and direction of bedding-plane slip movements are clearly shown by deformed cleavage at interfaces between movement zones.
>
> Toward the fold axis, beyond the zone of lateral change in the distinguishing lithic properties of unit 17, the fault plane is clearly evident and marked by cleavage distortion. The drag sense of this cleavage indicates reverse-fault movement; i.e., younger beds moved up and out of the synclinal core. The same plane of movement on the south limb of the syncline had the identical direction of that on the north limb, again interpreted from drag on cleavage. Thus, unit 18 has moved northward with respect to unit 16 *in* toward the synclinal axis. . . .
>
> Wedge faulting of massive sandstones resulting in anomalous bed thickening is an obvious indication of lateral shortening by compression. Figure 2 [same as Figure 160 of this report] shows one of many examples in these cuts of wedge faulting within massive sandstones. The fracture surface of the wedge is at a low angle to bedding and slip planes can be traced several feet into the massive sandstone unit (e.g., unit 19). Anomalous thickening in unit 19 causes depression of the underlying red siltstone. A low angle fracture plane results from readjustment of the more competent, massive sandstones during compressional stress of folding. The wedges observed here appear not to be the prefold types described by Cloos (1961, 1964).

## Relation of Surface and Subsurface Geology

Cross sections A, D, E, and G indicate the presumed subsurface structure at selected places in the mapped area. These cross sections are based on projection of surface data into the subsurface, not on actual subsurface data.

Two exploratory wells, the Harvey Smith #1 and the Graver Estate #1, have been drilled on the Lehighton anticline, and the log of the latter is presented in measured section 24. The Harvey Smith #1 well was drilled to 3,300 feet and never left the dark-gray shales of the Mahantango and Marcellus Formations. The drilling apparently traveled mainly down dip within the shales and offers nothing for subsurface interpretation.

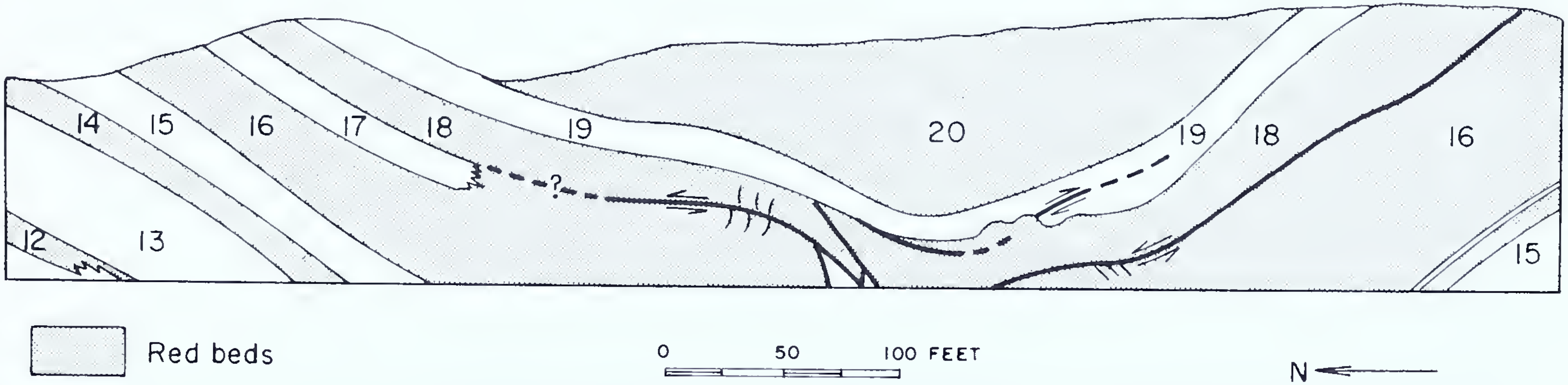


Figure 160. Faulting in axial portion of Weir Mountain syncline. Exposure is on east side of Pa. Route 248 a half mile north of Bowmanstown. Fault-movement directions and cleavage drag are shown, and bed numbers show stratigraphic succession. Diagram from Glaeser (1967).

The Graver Estate #1 well had a 15° deviation of the drill string toward the axis of the Lehighton anticline and intersected the Palmerton Formation at 4,620 feet, instead of at the expected 3,100 feet, based on simple graphical construction of uniform structure. Thus, faults are present in the subsurface that either do not extend to the surface or have not been detected at the surface.

## Sweet Arrow Fault Zone

The Sweet Arrow fault zone is a major structure in Pennsylvania and has been mapped for more than 80 miles in the State (Wood and Kehn, 1961; Wood and others, 1969). It extends from west of the Susquehanna River and is believed to die out near the east edge of the Palmerton quadrangle. Wood and his coworkers described the Sweet Arrow as a zone of one or two faults that dip moderately to the southeast at the surface and probably flatten at a depth of about 1 mile. Displacement is at least 3½ miles in places and is proved by anomalous structural relations and truncated stratigraphic units. The zone is one of the youngest faults in the area because it is not folded and it truncates many folds.

Wood and Kehn (1961) and Wietrzychowski (1963b) suggested that the intense folding in lithotectonic unit 3 was related to the Sweet Arrow fault, but this was discounted by Epstein and Epstein (1969), who suggested that the folds are part of a disharmonically folded sequence, as described under lithotectonic unit 3 above. It was also suggested under the section on décollements that the folds are not related to drag on the fault.

Epstein and Epstein (1969) believed that the Sweet Arrow fault did not extend into the Lehigh River area from the west, because it was felt that lithotectonic unit 4 followed the form surface of lithotectonic unit 3 (see their Figures 27 and 52). For example, it was shown that the rocks in lithotectonic unit 4 were overturned to the south, as were the underlying rocks. Subsequent mapping has shown that the rocks of lithotectonic unit 4 cannot parallel those of unit 3 in the subsurface. Thus, rocks of unit 3 are overturned to the southeast, whereas those of unit 4 are upright and dip to the northwest, and the Sweet Arrow fault must be present to resolve this geometric anomaly (see cross sections, Plate 1).

The fault zone is believed to be exposed in the Marcellus Formation along the Northeast Extension of the Pennsylvania Turnpike. Here, there are several prominent moderately southeast dipping shear zones, well-developed cleavage, and distorted cleavage (Figure 161). It is not known how much of this deformation is related to the Weir Mountain décollement. The southeast-dipping shear zones and sense of movement suggested by cleavage drag is evidence that the Sweet Arrow is a southeast-dipping fault.

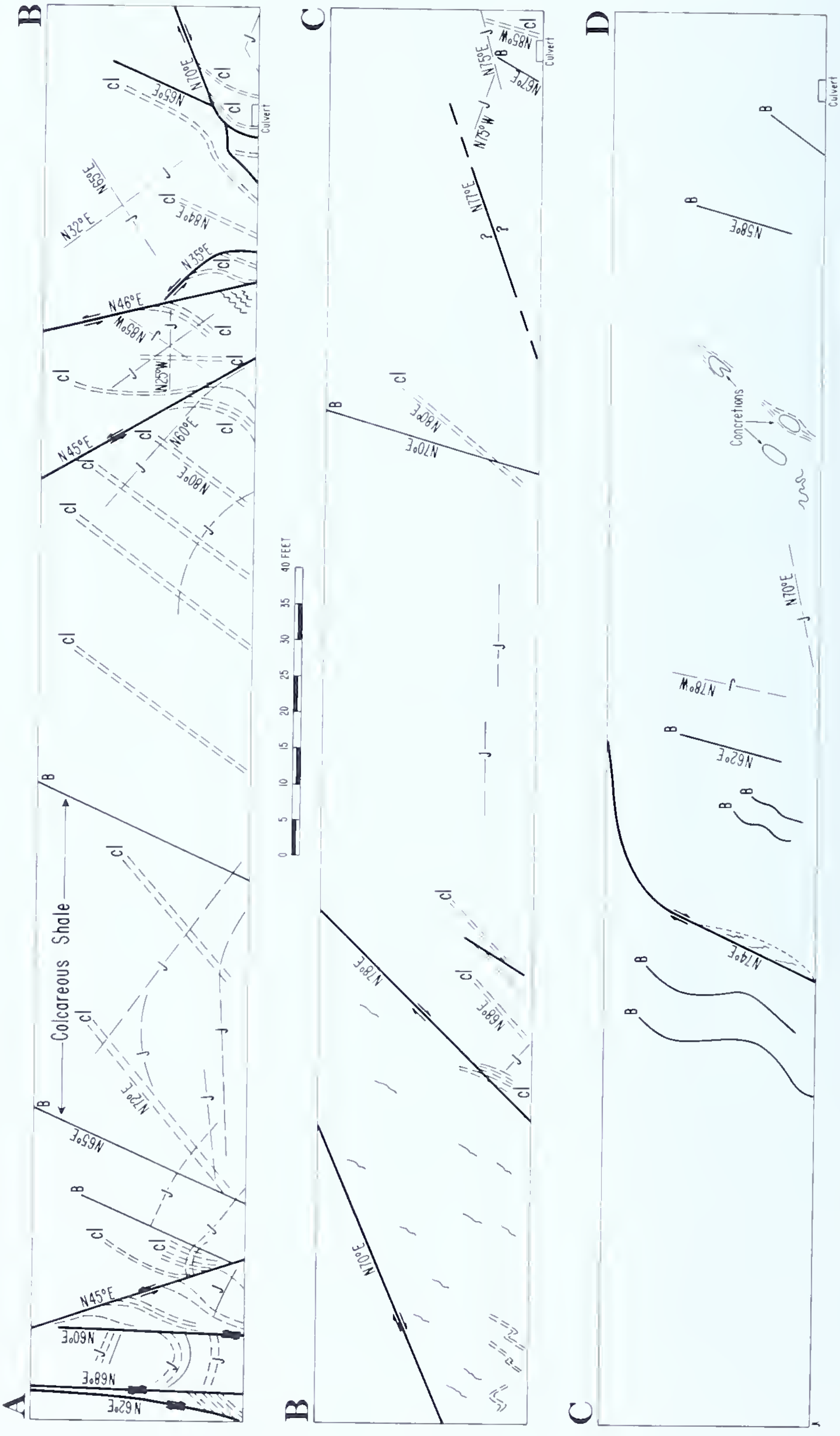


Figure 161. Cross section through the Marcellus Formation along the Northeast Extension of the Pennsylvania Turnpike at West Bowmans. Base of cross section is at road level. J, joint; B, bedding; cl, cleavage. Orientation of exposure face is about N15W. South end of cross section is at top of Buttermilk Falls Limestone and north end is at south side of bridge abutment for Pa. Route 895.

The fault zone is at least 300 feet wide in the exposure and may extend northward for an additional 600 feet. The fault, as shown on Plate 1, passes through the Marcellus outcrop on the Turnpike south of Pa. Route 895, but the part of the fault zone with the greatest shearing could be in the valley 500 feet northwest of the road. Based on construction of cross sections, the maximum displacement is probably about 1,000 feet. Because the fault is a southeast-dipping thrust, as shown in the cross sections, there must be a buried anticline in the footwall which places rocks of lithotectonic unit 3 south of and below the same rocks in the hanging wall. This fold is hypothetical and nowhere reaches the surface. Equally hypothetical is the tight syncline that the fault bisects.

The Sweet Arrow fault zone is believed to end near Little Gap because of the structural geometry in that area. However, a fault of unknown magnitude and attitude in the Mahantango and Marcellus Formations, which is indicated by abundant vein quartz float and offset stratigraphic units and which may be an imbricate fault related to the Sweet Arrow fault zone, was mapped for 4 miles east of Little Gap into the Kunkletown quadrangle (Sevon, unpub. data). The pieces of vein quartz are as much as 13 inches long and 7 inches wide and can be readily traced across fields not covered by colluvium or alluvium. The trace of this fault is not shown on Plate 1, but it lies near or several hundred feet north of the trace shown for the Sweet Arrow fault zone. Alternatively, because it parallels the strike of bedding, it may be a décollement or large bedding slip zone.

The vein quartz associated with this fault can be traced almost continuously between the north-south road through the Alliance Sand Company quarry (northwest of Palmerton) and Christian Corner about 4½ miles to the northeast. Along this line, the vein quartz float occurs in a narrow band near the base of the Mahantango Formation and is associated with crests of small hills. Between Christian Corner and Little Gap the surface is covered with colluvium, and location of in situ vein quartz is not possible. About one-half mile west of the eastern boundary of the mapped area, float of vein quartz occurs at two horizons within the Mahantango Formation. The lower occurrence is near the base of the Mahantango and may be the continuation of the fault zone occurring to the west. To the east, this fault zone rises stratigraphically within the Mahantango before all trace of the zone is lost about one-half mile east of the mapped area. A second fault zone occurs between the Centerfield fossil zone and the Nis Hollow siltstone zone of the Mahantango Formation and has been traced across almost half of the adjacent Kunkletown 7½-minute quadrangle (Sevon, unpub. data).

A fault trending slightly northwest from West Bowmans is indicated by topography and offset stratigraphic units. The attitude of this fault is

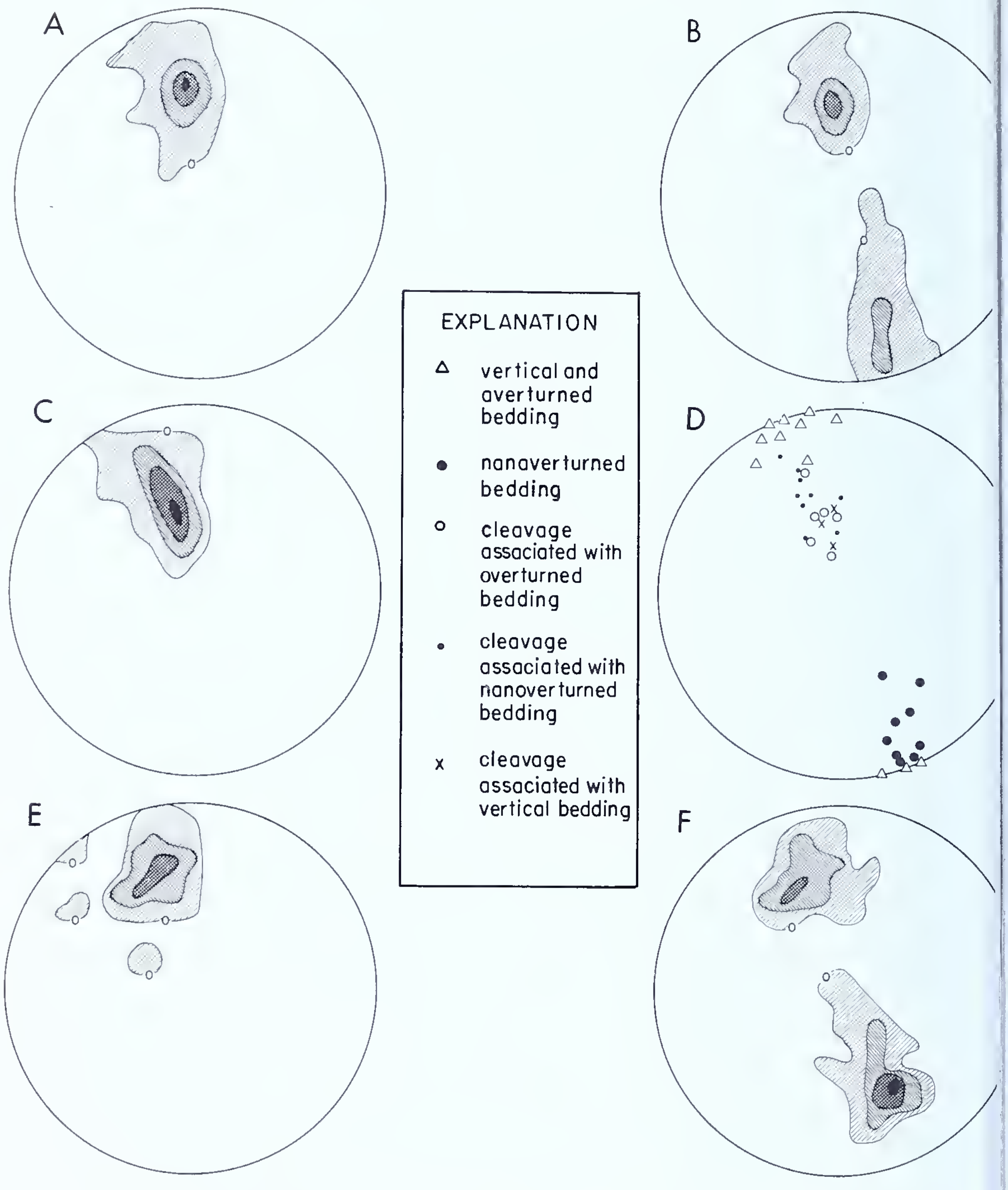


Figure 162. A. Equal-area lower hemisphere projection of 76 observations of slaty cleavage orientation in the Mahantango Formation on the south limb of the Weir Mountain syncline. Contours 0, 10, 20, 30 percent. B. Equal-area lower hemisphere projection of 24 pairs of observations of paired slaty cleavage and bedding orientations in the Mahantango Formation on the south limb of the Weir Mountain syncline. Contours 0, 5, 10 percent. Mean cleavage orientation: strike, N79E, dip 42S; mean bedding orientation: strike N75E, dip 66N. C. Equal-area lower hemisphere projection of 52 observations of slaty cleavage orientation in the Mahantango Formation on the north limb of the Lehighton anticline. Contours 0, 5, 10, 15 percent. D. Equal-area lower hemisphere projection of 19 observations of paired

not known, and the offset of fossil and siltstone zones suggests either a north-dipping normal fault or a south-dipping thrust fault, but a southwest-dipping fault associated with the Sweet Arrow fault is thought likely. A northeast-southwest-trending fault is exposed in a cut along the Lehigh Valley Railroad at West Bowmans. This fault plane strikes N54E and dips 22° south. The fault zone has a maximum thickness of 3 inches and may be only a reflection of weathering along the plane of weakness since no fault plug or breccia is present. The units adjacent to the fault do not have sufficiently well defined beds to permit determination of displacement.

## SMALL-SCALE STRUCTURES IN POST-ORISKANY ROCKS

### Slaty Cleavage

Slaty cleavage (Dennis, 1967, p. 21) is well developed in all shales on the steep south flanks of synclines of lithotectonic unit 4. Only the slaty cleavage of the Mahantango Formation is considered in detail, but similar structures occur in the shales of the Walcksville and stratigraphically higher Catskill units. Slaty cleavage is developed in the Marcellus Formation and is well exposed along the Northeast Extension of the Pennsylvania Turnpike (Figure 161).

Slaty cleavage in the Mahantango Formation is the dominant planar element on the steep south limb of the Weir Mountain syncline and the steep to overturned north limb of the Lehighton anticline (Figure 91). Cleavage is less well developed in the calcareous fossil zones and is not present in the siltstone zone of the formation. The slaty cleavage does not appear to have caused noticeable distortion of the bedding only locally detectable within the main body of the shale. Figure 91 shows a typical example of slaty cleavage developed in the Mahantango shale.

Figure 162A shows the slaty cleavage on the south side of the Weir Mountain syncline to have an average strike of N81E and a 50° south dip. Figure 162B (cleavage and bedding orientations) indicates an average angular separation of 108° between slaty cleavage and bedding. Figure 162C shows a similar strike (N76E) of slaty cleavage on the north limb of the Lehighton anticline, but a gentler dip (36° south). Figure

slaty cleavage and bedding orientations in the Mahantango Formation on the north limb of the Lehighton anticline. E. Equal-area lower hemisphere projection of 25 observations of fracture cleavage orientation in the Trimmers Rock Formation on the south limb of the Weir Mountain syncline. Contours 0, 2.5, 5 percent. F. Equal-area lower hemisphere projection of 24 observations of paired fracture cleavage and bedding orientations in the Trimmers Rock Formation on the south limb of the Weir Mountain syncline. Contours 0, 2.5, 5, 7.5 percent.

162D indicates that while there is extreme variation in bedding dip on this fold limb, there is only small variation of cleavage dip. The average angular separations between bedding and cleavage calculated from this plot are 114° for cleavage and nonoverturned bedding and 51° for cleavage and vertical or overturned bedding. Another illustration of the constancy of slaty cleavage attitude in association with considerable variation in bedding attitude is shown in Figure 163.

Slaty cleavage is not well developed in the Mahantango Formation on the north limb of the Weir Mountain syncline. This is probably due to the fact that the average dip of cleavage (50° and 36° south) on opposite limbs of the two adjacent folds is similar to the average dip of the bedding (33° south) on the south limb of the Weir Mountain syncline so that cleavage is difficult to detect except in good exposures.

Slaty cleavage is very well developed on the north limb of the Lehighton anticline and has been used extensively to determine overturned beds. Variations in cleavage dip are considerable, but the steepest dips appear to be chiefly near the main anticlinal axis (Plate 1).

Some of the cleavage developed in the Walcksville Member of the Catskill Formation north of Bowmanstown has been folded (Figure 164).

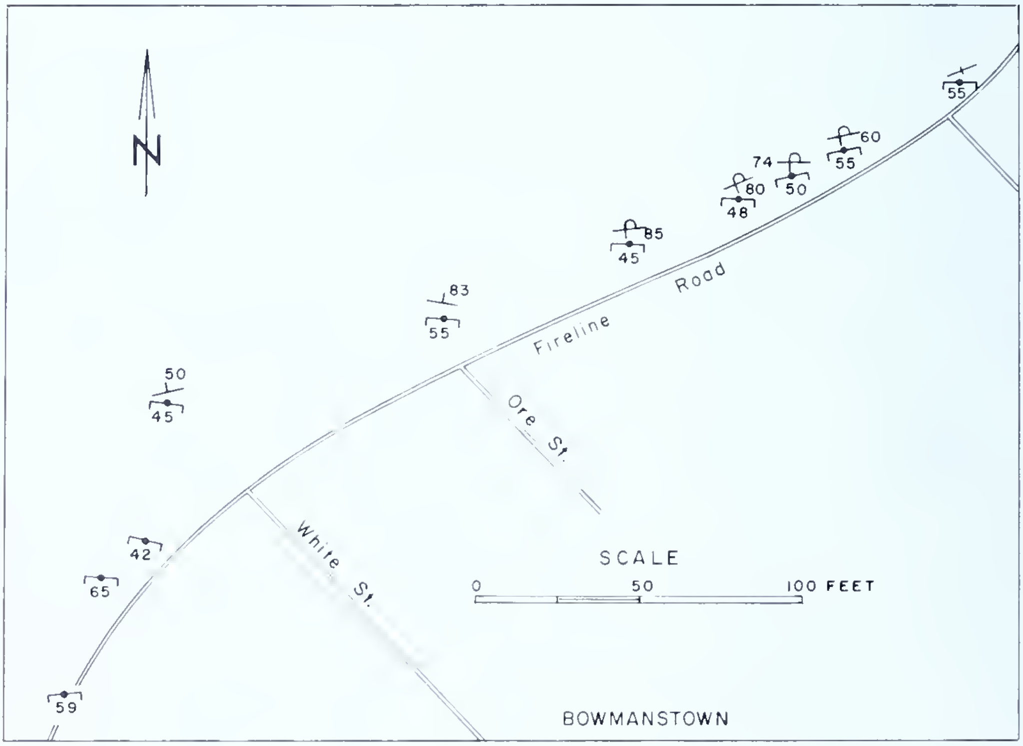


Figure 163. Variation in slaty cleavage and bedding orientations in Mahantango shale in roadcut along Fireline Creek at the north edge of Bowmanstown. Note constancy of cleavage orientation and variation of bedding orientation.

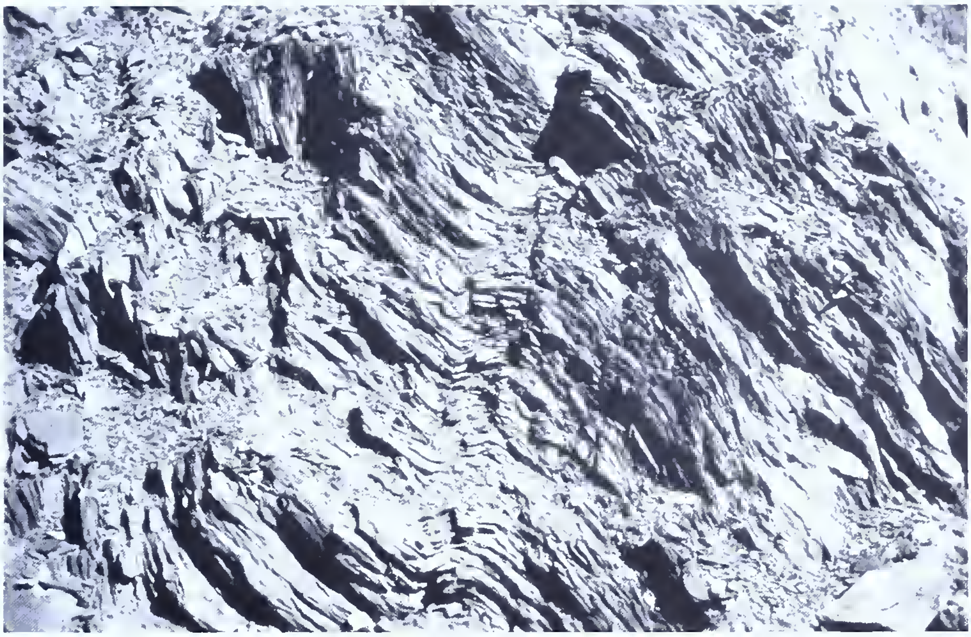


Figure 164. Folded cleavage in red shales of the Walcksville Member of the Catskill Formation. Outcrop occurs near the south end of the second long roadcut north of Bowmanstown on the east side of Pa. Route 248. Photograph by A. A. Drake, Jr.

Folding of this cleavage indicates some deformation subsequent to cleavage development, but the extent of this cleavage deformation elsewhere in the mapped area is not known.

Thin sections of the Mahantango Formation show that the micaceous minerals (illite-sericite) have a preferred orientation parallel to slaty cleavage, and minute fractures along which weathering is proceeding tend to be parallel to slaty cleavage rather than bedding.

## Fracture Cleavage

Fracture cleavage is well developed in the Trimmers Rock Formation on the south side of the Weir Mountain syncline. According to Turner and Weiss (1963, p. 98), fracture cleavage is essentially a variety of closely spaced discrete parallel fractures that do not pervade the entire rock mass and are independent of preferred orientation of mineral grains. The fracture cleavage described here seems to correspond to this definition.

The fracture cleavage in the Trimmers Rock Formation has an orientation similar to that of slaty cleavage in the underlying Mahantango Formation and has an average strike of N74E and a 55° south dip (Figure 162E). Fracture cleavage is most common in the more massive

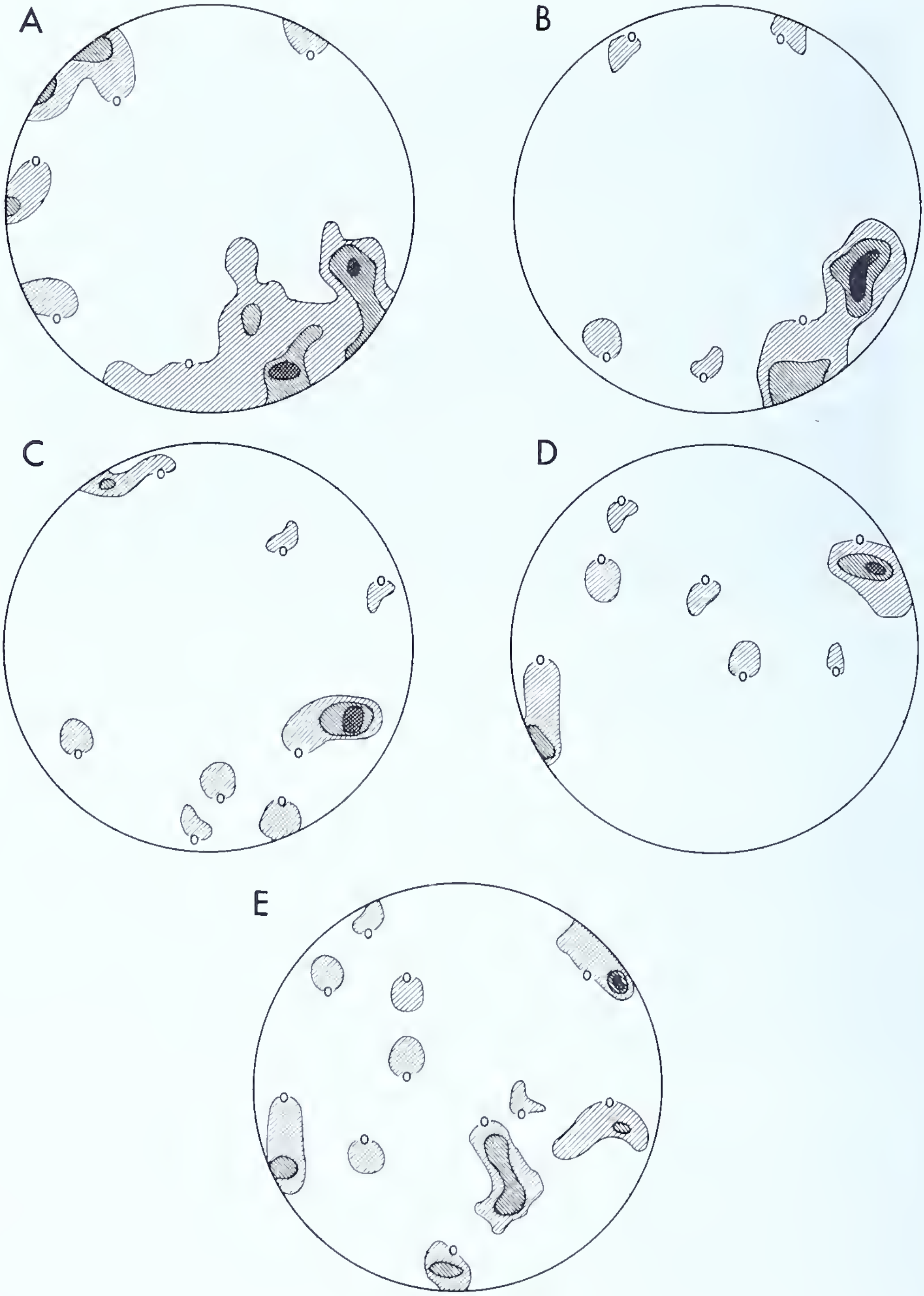


Figure 165. A. Equal-area lower hemisphere projection of 40 observations of joint orientation in the Mahantango Formation on the north limb of the Weir Mountain syncline. Contours 0, 2.5, 5 percent. B. Equal-area lower hemisphere projection of 27 observations of joint orientations in the Trimmers Rock Formation on the north limb of the Weir Mountain syncline. Contours 0, 2.5, 5 percent. C. Equal-area lower hemisphere projection of 18 observations of joint orientations in the Towamensing Member of the Catskill Formation on the north limb of the Weir Mountain syncline. Con-

beds (1 to 4 feet thick) of the formation and often passes directly into slaty cleavage in interbedded shales. Bedding surfaces show the fractures to be somewhat sinuous intersecting planes with regular spacing of 1 to 3 inches and sometimes a suggestion of movement normal to bedding along the fractures. The average angular distance between bedding and fracture cleavage in the Trimmers Rock indicated in Figure 162F is 94°.

Fracture cleavage is present in other units within the mapped area on the steep south limbs of the syncline, but is seldom exposed as well as in the Trimmers Rock Formation. Fracture cleavage provides a source of weakness which aids in rock disintegration and control of the size and shape of weathered-rock materials.

## Joints

Observations made during mapping and plots shown in Figure 165 allow some generalizations about joint systems in the mapped area.

The unit most prominently jointed is the Palmerton Formation (Figure 85), although similar joint systems occur in the underlying Schoharie-Esopus and Ridgeley Formations. The plot of joint poles in Figure 165E indicates a variety of joint systems, and a study by Wietrzychowski (1964, p. 33) indicated an even larger range of joint sets. His study included about 100 joints exposed on Stony Ridge a mile west of Walkton. He noted 13 narrowly defined groups which included orientations between N79W and N80E and dips 9° west and 20° east.

Spacing of joints in the Palmerton, Schoharie-Esopus, and Ridgeley Formations is variable and ranges from the relatively uniform wide spacing (several feet) in the Palmerton (Figure 85) to very irregular close spacing (a few inches) in all the units. In general, the greater the complexity of folding, the greater the number of joints and the closer the spacing. The abundance of joints and their intensive development within the three formations contribute greatly to the disintegration of these units and the control of their disintegration shapes.

Although joints occur within the Mahantango and Trimmers Rock Formations and the Towamensing Member in the south limb of the Weir Mountain syncline, dominance of slaty cleavage in the Mahantango and lack of outcrops of the other units offer insufficient data for worthwhile assessment. Nevertheless, some joint data for these formations are presented on Plate 1.

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tours 0, 2.5, 5 percent. D. Equal-area lower hemisphere projection of 18 observations of joint orientations in the Trimmers Rock and Catskill Formations on the north side of the Lehighton anticline. Contours 0, 2.5, 5 percent. E. Equal-area lower hemisphere projection of 25 observations of joint orientations in the Ridgeley, Schoharie-Esopus, and Palmerton Formations along Stony Ridge. Contours 0, 2.5, 5 percent.

Fractures are abundant in the Mahantango on the south side of the Weir Mountain syncline and have a great variety of orientations. Some of these fractures are curved, and in combination with slaty cleavage, bedding, and joints produce an ellipsoidal disintegration structure illustrated in Figure 92 and discussed earlier under the stratigraphy of the Mahantango Formation.

Figure 50A, B and C indicates a consistent joint development on the north side of the Weir Mountain syncline. Two main joints exist, one having a N22E strike and a dip of 66NW and the other a N65E strike and a 77°-83° north dip.

Spacing of joints in these units is variable and was not studied closely during this investigation. In general, those joints with orientation parallel or subparallel to bedding orientation have spacings of a few inches, while joints with orientations normal or subnormal to bedding orientation have spacings of a few feet.

## ENVIRONMENTAL GEOLOGY

Environmental geology is the evaluation, utilization, and application of geologic factors which interact with man and his works. This section is a guide to the use of the geologic map and geologic information in this report and may aid in the solutions of environmental problems that are of concern to those planners involved with land utilization and resource management. It should not be used in lieu of detailed onsite studies by professional geologists and engineers.

The Lehighton and Palmerton quadrangles straddle the two sections of the Valley and Ridge physiographic province (Figure 1). The topography in these sections has profoundly controlled the development of the area. Most notably, in the Appalachian Mountain section (the area north of Blue Mountain), the steep slopes of the mountains have generally precluded their use for most types of development other than recreation, and they have generally remained as wooded areas. The major population centers, such as Jim Thorpe, Lehighton, and Palmerton, are located along the Lehigh River and in the major northeast-trending valleys, which have determined the location of the main transportation routes. In the Great Valley section, south of Blue Mountain, there is no pronounced linear pattern to the topography, and the transportation network is more irregular than in the section to the north. The thicker, more fertile soil in the Great Valley section has favored the use of most of the land for agriculture and grazing.

Because of the lack of favorable industrial and agricultural incentives, no large urban centers, such as Bethlehem and Allentown, have grown up as they have in the flatter part of the section underlain by limestone south of the quadrangles. Because there is high-quality slate in the Martinsburg Formation in the Great Valley section, an important slate industry has developed, although all the quarries in the quadrangles here being described are presently abandoned. The cultural development of the Great Valley is given in reports on Lehigh and Northampton Counties by Miller and others (1941, 1939).

The environmental geology section of this report is subdivided into several topics for the purpose of convenience. Included are a discussion of the geologic map, engineering characteristics of the map units, soils, the climate of the area, water supply, and mineral resources. For land-use purposes, many of these topics are interrelated. Optimal utilization and constructive modification of the geologic factors in any area are dependent upon an understanding of these factors and a willingness to precede development with planning.

## GEOLOGIC MAPS

The data in this section are related to specific rock units (formations, for example) whose distribution is shown on the geologic maps (Plates 1 and 2) accompanying the report. These two maps emphasize different aspects of the geology: the bedrock map (Plate 1) shows the distribution of the rock units by means of the colors explained in the map explanation and has the overlying surficial deposits indicated only by purple lines for contacts and symbols; and the surficial map (Plate 2) shows the surficial deposits in color and the bedrock only by purple contacts and symbols.

## ROCK CHARACTERISTICS AND PROPERTIES

The main characteristics of each rock unit in the area are summarized in Table 15. A brief description of each characteristic is given below.

### Map Symbol and Formation or Member

The map symbol and name for each rock unit are the same as on Plates 1 and 2, and allow direct translation of information presented in Table 15 to specific areas on the map. Unless otherwise indicated, the rock characteristics discussed below are constant throughout the area of occurrence of each map unit.

### Thickness

The maximum known thickness (measured perpendicular to bedding) is given for each rock unit. Where thickness is variable, the known extent of variation is indicated.

## Lithology

The main types of a mapped rock unit are given. Detailed information on the rocks and their variability is presented in the text discussion of each mapped unit.

## Infiltration Capacity

Infiltration capacity is the maximum rate at which a rock unit, when in a given condition (e.g., dry, saturated) can absorb falling rain or melting snow. This infiltration capacity affects the ground-water recharge capacity of a given unit and also the unit's utility for septic-system sewage disposal. Almost all of the rocks in the area are relatively impermeable. However, all the rocks in the area possess an intersecting complex of partings along bedding, cleavage, and joint planes. These parting planes create a unit permeability unrelated to the actual rock type. This permeability will vary with depth of rock below the surface and with structural position; it can generally be evaluated accurately by examination of a specific site.

One generality can be made for the mapped area. The steeper dipping beds on the south limbs of synclines are more intensely jointed than the north limbs, tend to have well-developed cleavage, and have undergone more movement along bedding planes than the north limbs. These planes of weakness and separation within the rock result in a greater naturally induced permeability in rocks on the south limbs of synclines than in rocks on the north limbs of synclines.

Good infiltration capacity is most important where septic-sewage-disposal drainage fields are in use or are projected to be installed. Adequate infiltration capacity, as determined by percolation tests,, is required by law in Pennsylvania. Any drainage field placed directly on or in any of the bedrock materials of the mapped area may have inadequate drainage because of low to moderate infiltration capacity. However, throughout the mapped area some of the solid bedrock is mantled with 10 or more feet of broken rock material underlying the soil. This mantle of broken rock will normally have adequate infiltration capacity to handle homesite septic systems. The ratings used in Table 15 for evaluation of infiltration capacity have the following meanings: low—infiltration capacity inadequate for septic systems during wet periods, but may be adequate during dry periods; moderate—infiltration capacity adequate for septic systems except during excessively wet periods; high—infiltration capacity adequate for systems at all times. The ratings presented in Table 15 are generalized for the average situation in the mapped area—that is, for a location on a gentle or moderate slope 15 feet or more above a nearby stream. Locations in low areas near the same elevation as nearby streams will normally have lower infiltration capacity because of higher ground-water tables.

Adequate infiltration capacity for a septic-sewage-disposal system is not a guarantee that such a system would be effective. A unit with high infiltration may transport effluent rapidly without natural purification to some unwanted location and result in a pollution problem. Other factors besides percolation rate are important in determining the feasibility for septic-tank installation. These factors must be examined and evaluated at the building site. They include:

1) Slope. Land slopes greater than 10 percent may result in surface seepage.

2) Depth to bedrock. Ideally there should be a soil zone of at least four feet below the septic-tank installation and above solid bedrock for proper filtration and absorption of the effluent. Depth to bedrock may be determined at a specific site by trenching, drilling, or by reference to water-well records.

3) Depth to water table. In general, the depth to high-water table is greater than 10 feet in the Lehighton and Palmerton quadrangles, except near streams and other low-lying areas. In those areas where the water table is near the surface, the soil is saturated with water so that water from septic tanks cannot be absorbed.

4) Flood-prone areas. Areas subject to flooding should be avoided because of saturation of the field during flooding and damage to the system.

5) Proximity to water bodies and water wells. The septic system must not be located so that effluent will pollute nearby water wells or lakes and streams.

## Aquifer Potential

The aquifer potential of any given unit is related to its infiltration capacity (discussed above), its topographic position, and its structural position. A few generalities related to these factors are:

1. Aquifer potential tends to be most favorable in topographically low positions (i.e., valley bottoms), and least favorable in topographically high positions (i.e., hilltops).

2. Aquifer potential tends to be most favorable near the axes of synclines and on adjacent limbs and least favorable near the axes of anticlines. Water-yield data for specific units in the area are discussed in the section on ground water.

3. Glacial deposits, particularly outwash gravels, because of their high infiltration capacity, would seem to have high aquifer potential. However, the same characteristics which allow infiltration also allow rapid flow of water out of a unit and unless the deposit occupies a position which will

## Table 15. *Summary of Environmentally Significant Properties of*

(See text for discussion

| Map Symbol | Formation or Member | Thickness (ft) | Lithology | Infiltration Capacity | Aquifer Potential |
|---|---|---|---|---|---|
| Qal | Alluvium | 0–15 | Sorted beds of clay, silt, sand, and boulders | Moderate to high | Unknown; probably low |
| Qc | Colluvium | 0–25+ | Unsorted clay, silt, sand, and boulders | Moderate to high | Unknown; probably low |
| Qsr | Shale-chip rubble | 0–30+ | Shale chips | High | Low to none |
| Qbf | Boulder field | 10+ | Sandstone boulders | High | Low to none |
| Qit | Illinoian(?) till | 0–20+ | Unsorted clay, silt, sand, and boulders | Low to moderate | Unknown; probably low |
| Qio | Illinoian(?) outwash | 0–80 | Sorted beds of clay, sand and gravel | Moderate to high | Unknown; probably low |
| Mmc | Mauch Chunk | 2000+ | Red sandstone, siltstone | Low to moderate | Unknown; probably low to moderate |
| Mp | Pocono | 759 | Conglomerate, sandstone | Low to moderate | Unknown; probably moderate |
| MDsk | Spechty Kopf | 548 | Diamictite, mudstone, sandstone | Low to moderate | Unknown; probably moderate |
| Dcd | Duncannon | 865 | Conglomerate, sandstone, siltstone | Low to moderate | Unknown; probably moderate |
| Dccf | Clark's Ferry | 904 | Conglomerate, sandstone | Low to moderate | Unknown; probably moderate |
| Dcbe | Berry Run | 985 | Sandstone, some siltstone and conglomerate | Low to moderate | Unknown: probably moderate |

Various Lithologic Units in the Lehighton-Palmerton-Jim Thorpe Area

of column headings)

| Weathering Character | Slope Stability | Excavation Difficulty | Foundation Support Strength | Mineral Resources |
|---|---|---|---|---|
| Unconsolidated | Low to moderate; toe should not be undercut; top should not be loaded | Low | Low; excavate to bedrock for heavy structures | Aggregate |
| Unconsolidated | Low to moderate; toe should not be undercut; top should not be loaded | Low; boulders may be encountered | Low to moderate | Building stone |
| Unconsolidated | Low to moderate; toe should not be undercut; top should not be loaded | Low | Low, excavate to bedrock for structures | Road metal; lightweight fill |
| Very slow boulder disintegration; boulders loose but large | Low to high | Difficult | Unknown; probably low to moderate | Building stone |
| Unconsolidated | Low to moderate; toe should not be undercut; top should not be loaded | Low; boulders will be encountered | Low; excavate to bedrock for heavy structures | Impermeable fill; building stone |
| Unconsolidated; gravel pebbles chemically weathered and soft | Low to moderate; toe should not be undercut; top should not be loaded | Low | Low; excavate to bedrock for heavy structures | |
| Moderate disintegration; moderate depth to bedrock | Moderate to high | Moderate; may require some auxiliary breaking or blasting | High | Aggregate; roofing granules |
| Moderate disintegration; low to moderate depth to bedrock | Moderate to high | Difficult | High | Aggregate; building stone |
| Moderate disintegration; low to moderate depth to bedrock | Moderate to high | Moderate to difficult | High | Road base course |
| Moderate disintegration; low to moderate depth to bedrock | Moderate to high | Difficult | High | |
| Moderate disintegration; low to moderate depth to bedrock | Moderate to high | Difficult | High | Flagstone; crushed rock |
| Moderate disintegration; low to moderate depth to bedrock | Moderate to high | Difficult | High | Flagstone; crushed rock |

Continued

Table 15.

| Map Symbol | Formation or Member | Thickness (ft) | Lithology | Infiltration Capacity | Aquifer Potential |
|---|---|---|---|---|---|
| Dcsr | Sawmill Run | 424 | Sandstone; red siltstone in bottom, middle and top | Low to moderate | Unknown; probably moderate |
| Dcp | Packerton | 416 | Sandstone; minor conglomerate, siltstone, shale | Low to moderate | Unknown; probably moderate |
| Dclr | Long Run | 2363 | Red sandstone, siltstone, shale | Low to moderate | Yields moderate quantities of water; moderate well depth |
| Dcbr | Beaverdam Run | 963 | Brown siltstone | Low to moderate | Unknown; probably moderate |
| Dcw | Walcksville | 645 | Red to green sandstone, siltstone, shale | Low to moderate | Yields moderate quantities of water; moderate well depth |
| Dct | Towamensing | 190 | Sandstone; siltstone in middle | Low to moderate | Unknown; probably low to moderate |
| Dtr | Trimmers Rock | 1042 | Well-bedded siltstone, shale | Low to moderate | Yields low to moderate quantities of water; moderate to deep well depth |
| Dmh | Mahantango | 2100+ | Siliceous shale | Low to moderate | Yields moderate quantities of water; moderate well depth |
| Dmbf (upper part) | Marcellus | 800+ | Clayey shale | Low to moderate | Unknown; probably low |
| Dmbf (lower part) | Buttermilk Falls | 40 | Limestone; calcareous shale | Moderate to high | Unknown; probably low |
| Dp | Palmerton | 100 | Quartz sandstone | Low to moderate | Unknown; probably low |
| Dse | Schoharie-Esopus | 12–76 | Siltstone | Low to moderate | Unknown; probably low |
| Do (upper part) | Ridgeley | 8–50 | Conglomeratic quartz sandstone | Low to moderate | Unknown; probably low |

*(Continued)*

| Weathering Character | Slope Stability | Excavation Difficulty | Foundation Support Strength | Mineral Resources |
|---|---|---|---|---|
| Moderate to high disintegration; moderate depth to bedrock | Moderate; siltstone beds disintegrate rapidly | Moderate to difficult | High | |
| Moderate disintegration; low to moderate depth to bedrock | Moderate to high | Difficult | High | Crushed rock |
| Moderate to high disintegration; moderate depth to bedrock; forms topographic low | Moderate to high | Moderate; may require some auxiliary breaking | High | Roofing granules |
| Moderate disintegration; low to moderate depth to bedrock | Moderate to high | Moderate; may require some auxiliary breaking | High | Roofing granules |
| Moderate disintegration; moderate depth to bedrock | Moderate to high | Moderate; may require some auxiliary breaking | High | Roofing granules |
| Moderate disintegration; low to moderate depth to bedrock | Moderate to high | Moderate; may require some auxiliary breaking | High | |
| Moderate disintegration; moderate depth to bedrock | Low to moderate; disintegrates rapidly when exposed | Moderate; may require some auxiliary breaking | High | |
| Moderate disintegration; moderate to deep depth to bedrock | Low to moderate; disintegrates rapidly when exposed and cleavage is prominent | Low to moderate | Moderate to high | Fill |
| Moderate to high disintegration; moderate to deep depth to bedrock | Low; disintegrates rapidly when exposed | Low | Moderate | |
| Deep leaching; deep depth to bedrock | Low | Low | Low | |
| Variable; low to high disintegration; low to deep depth to bedrock | Low to high | Variable; low to difficult; usually requires blasting | Moderate | Sand |
| Low to moderate disintegration; low to moderate depth to bedrock | Moderate | Moderate to difficult; may require some auxiliary breaking | Moderate to high | |
| Moderate to high disintegration; low to moderate depth to bedrock | Moderate | Moderate to difficult; may require some auxiliary breaking or blasting | Moderate | Sand |

Continued

Table 15.

| Map Symbol | Formation or Member | Thickness (ft) | Lithology | Infiltration Capacity | Aquifer Potential |
|---|---|---|---|---|---|
| Do (lower part) | Shriver-New Scotland | 45–75 | Calcareous shale, chert, sandstone | Low | Unknown; probably low |
| DSsd | Stormville-Decker | 140 | Siltstone, sandstone, limestone | Low to moderate | High; moderate to deep well depths |
| Sbv | Bossardville | 100 | Limestone | Low | Unknown; probably low |
| Spi | Poxono Island | 300–800 | Shale, siltstone, dolomite, limestone | Low | Unknown; probably moderate to high |
| Sb | Bloomsburg | 1500 | Siltstone, shale, sandstone | Low to moderate | Moderate to high; moderate to deep well depth |
| Ssl | Lizard Creek | 1225 | Sandstone, siltstone, shale | Low to moderate | Unknown; probably low |
| SOsm | Minsi | 225 | Sandstone, conglomerate | Low to moderate | Unknown; probably low |
| SOsw | Weiders | 50–220 | Conglomerate, sandstone | Low to moderate | Unknown; probably low |
| Omp | Pen Argyl | 6000 | Slate | Low | Moderate to high; moderate well depth |
| Omr | Ramseyburg | 3000 | Slate, sandstone | Low to moderate | Moderate; moderate well depth |

prevent outflow of water (e.g., a depression filled with gravel) the unit will generally yield very little water. This characteristic of water loss from such permeable materials also detracts from their use in sewage disposal since these materials provide little renovative capacity for sewage contaminants. The ratings used for the evaluation of aquifer potential in Table 15 have the following meanings: low yield—less than 10 gallons per minute; moderate yield—about 20 gallons per minute; high yield—over 50 gallons per minute; moderate well depth—100 to 150 feet.

*(Continued)*

| Weathering Character | Slope Stability | Excavation Difficulty | Foundation Support Strength | Mineral Resources |
|---|---|---|---|---|
| Moderate to high disintegration; deep leaching; low to deep depth to bedrock | Low to moderate | Low to moderate | Low to moderate | |
| Deep leaching; deep depth to bedrock | Low to moderate | Low to moderate | Low to moderate | |
| Low disintegration; low depth to bedrock | Moderate to high | Moderate to difficult | High | Aggregate; agricultural lime |
| Moderate disintegration; low to moderate depth to bedrock | Moderate | Moderate | Moderate to high | |
| Low to moderate disintegration; low to moderate depth to bedrock | Moderate to high | Low to moderate; some beds may require blasting | High | Road metal |
| Low to moderate disintegration; low to moderate depth to bedrock | Moderate to high | Low to difficult; weathered shale and siltstone may be readily excavated with light machinery | High | |
| Low disintegration; low depth to bedrock | Moderate to high | Difficult; very slow drilling | High | Building stone; riprap |
| Low disintegration; low depth to bedrock | Moderate to high | Difficult; very slow drilling | High | Building stone; riprap |
| Low to moderate disintegration; low to moderate depth to bedrock | Moderate to high | Low to difficult; slate bedrock may require blasting | Moderate to high | Slate; road metal; lightweight aggregate |
| Low to high disintegration; low to moderate depth to bedrock | Moderate to high | Low to moderate | Moderate to high | Road metal |

## Weathering Characteristics

Weathering of a given unit depends on the physical characteristics of the unit, the climate, the topographic position, and the vegetation. Weathering occurs by chemical alteration and physical disintegration. The most prominent form of weathering in the mapped area is physical disintegration. Exceptions are the Illinoian(?) glacial deposits and the Buttermilk Falls Limestone, Shriver Chert, and New Scotland, Coeymans, and Decker Formations, which are highly susceptible to chemical alteration. Physical disintegration is closely related to the number of parting planes within a given unit and is thus aided by closely spaced bedding, cleavage, and joints. Therefore, greater physical disintegration may be expected on the steeper dipping south limbs of synclines in the area, since this is the position of greatest development of planes of separation. The data presented in the section on ground water indicate that solid bedrock is encountered generally at depths greater than 35 feet. The range of depths to bedrock is relatively large (1 to more than 150 feet). However, the greater depths to bedrock (over 35 feet) may reflect a susceptibility of highly fractured bedrock to breakage during drilling rather than reflect actual weathered bedrock. The ratings used for the evaluation of disintegration susceptibility in Table 15 are relative and only estimate the rapidity and extent of breakdown. The depths to bedrock are based on well data and in general mean: shallow—0 to 20 feet; moderate—21 to 50 feet; deep—over 50 feet.

## Slope Stability

Both natural and artificial slopes occur in the mapped area. The only evidence of natural slope instability in the area is a landslide-mudflow deposit on the north side of Bear Mountain east of Jim Thorpe. This slide appears to be quite old and presumably resulted from extreme loading of colluvium by water. The probability of a reoccurrence of such a slide is low, since there appear to be no similar environmental situations in the area. However, thick, stable talus and colluvium deposits present on many slopes are potentially unstable when modified by man.

Undercutting the toe of a slope is the primary modification of concern. This occurs mainly during highway construction and housing development. In general, undercutting a slope composed of any unconsolidated material increases its instability. There is no evidence in the mapped area of rapid mass movement resulting from modification of a slope composed of unconsolidated materials, but there are several examples of accelerated creep (slow mass movement) which have resulted from undercutting these slopes.

The second modification of concern is loading the upper part of the slope (e.g., construction of buildings or highways). Such loading should be done only after consideration of the slope character and its potential weakness. In general, unconsolidated materials (e.g., colluvium, talus) have a greater instability potential than consolidated materials. However, bedrock stability in both undercutting and upper slope loading situations will depend on the dip and strike of the beds relative to the slope (these are shown on the geologic map, Plate 1), and the abundance and nature of planes of weakness (e.g., bedding planes, cleavage, joints, faults). Situations in which planes of weakness parallel the slope or dip less steeply but in the same direction as the slope should be treated with special care.

Most man-made cuts warrant careful evaluation before the cut is made. Such evaluation should include determination of planes of weakness, their susceptibility to failure and the type of failure expected. This evaluation must be made even though the rock is rated moderate or high in slope stability. Valuable information can often be gained from existing roadcuts in the same rock material.

Artificial cuts in bedrock are numerous in the mapped area and indicate that, although no major slope failures have resulted from the cuts, the susceptibility of the rock to mechanical distintegration has been increased. The reaction of any given rock to maximum weathering exposure depends largely on the nature of its planes of weakness; the greater the number and the closer the spacing of such planes, the greater the susceptibility to mechanical disintegration. For example, the large exposure of Trimmers Rock Formation along Pa. Route 248 immediately north of Bowmanstown has abundant planes of weakness and disintegrates rapidly. In contrast, extensive exposures of rocks in the Berry Run, Clark's Ferry, and Duncannon Members of the Catskill Formation along U.S. Route 209 south of Jim Thorpe disintegrate at a somewhat slower rate as a result of fewer and more widely spaced planes of weakness. The ratings used for evaluation of slope stability in Table 15 are only relative and have no standard measure. In general, an artificial slope with a steep slope (vertical to 45 degrees), rated low in stability, would fail through gravity movement or very rapid rock disintegration along planes of weakness. Artificial slopes of moderate stability would fail only under unusual circumstances (such as earthquakes), but might have some rock disintegration along planes of weakness. Slopes of high stability would be trouble free.

## Excavation Difficulty

Unconsolidated materials in the area will generally present no difficulty to excavation except that some colluvial and till deposits may contain large boulders. Excavation difficulty of bedrock materials will depend upon the depth of mechanical disintegration, which is closely related to the planes of weakness within the rock. Only those units with closely spaced joints and bedding planes (e.g., Trimmers Rock Formation, Towamensing Member of the Catskill Formation) or good cleavage development (e.g., Walcksville and Long Run Members of the Catskill Formation) will be relatively easy to excavate to moderate depths. The more massive units with widely spaced joints (e.g., Packerton and Clark's Ferry Members of the Catskill Formation) will normally be difficult to excavate. The ratings used to evaluate excavation difficulty in Table 15 are: low difficulty excavation—backhoe and shovel operations proceed easily; moderate difficulty excavation—may require break-up of harder beds with tractor-ripper; difficult excavation—requires blasting. This is a general guide based on rock type.

### Foundation Support Strength

Bedrock in the area should give moderate to good foundation support strength for almost any type of structure. However, depth to solid bedrock is variable in the area and the support strength of the soil and broken rock will be less than that of solid bedrock. The foundation support strength of unconsolidated materials will depend on the nature of the material, slope, and moisture conditions, but generally it will be low. The ratings of foundation support strength used in Table 15 are: low—support largely by floating foundations or piers sunk into adjacent high-support strength units; moderate—may require some pier support for stability; high—structures supported by conventional footings.

### Mineral Resources

The potential economic products of the area are discussed in detail in the section on mineral resources and the listing in Table 15 serves only as a reference to that section.

## SOILS

The soils of the mapped area are covered in soil reports for Carbon (Fisher and others, 1962) and Lehigh (Carey and Yaworski, 1963) Counties. These reports describe the soils, interpret their land capability, woodland use and engineering properties, and present a soils map at a scale of 1:20,000.

A comparison of the soils map and soils description with the geologic maps accompanying this report (Plates 1 and 2) shows some differences between the soil survey interpretation of parent materials and the lithologies shown on the maps accompanying this report. These differences do not appear to be significant from the environmental point of view and presumably reflect only different interpretations of the regolith.

## CLIMATE

The Lehighton and Palmerton quadrangles are under the influence of a humid middle-latitude continental climate (Strahler, 1951, p. 349, 374-375). This climate results from "repeated invasions and interactions of tropical and polar airmasses" which have contrasting characteristics. The presence of numerous mountains, ridges and valleys causes considerable local variation in climatic conditions, particularly in the form of frost pockets in the valleys and deflection of storms which results in wide differences in local rainfall.

Rainfall is ample throughout the year (Figures 166 and 167), but highest in the summer when tropical air masses dominate. The data in Figures 166 and 167 suggest that Blue Mountain may have a rain-shadow effect on precipitation, resulting in 5 to nearly 7 inches per year less rainfall south of Palmerton than at Jim Thorpe. Figure 168 shows the distribution of precipitation at Jim Thorpe in years of rainfall extremes and Table 16 indicates the relative distribution of rain days and monthly snowfall amounts.

Annual temperature range for the area is large (Figure 169); the cold winter temperatures result from frequent continental-polar air-mass invasions. The relationship between temperature, snowfall and peak stream discharge is discussed below in the section on surface water. Table 16 indicates the distribution of frost days. Frosts generally do not occur between May 1 and October 8, but frost extremes have occurred on May 29 and September 8. The length of the growing season is about 160 days.

Winds in the area are mainly from the west, although some change to the north occurs in winter, particularly at higher elevations. Tornadoes have not been observed in Carbon County, but a few tornadoes have been observed in Lehigh and Northampton Counties (Dailey, 1970).

## URBAN AND INDUSTRIAL WASTE DISPOSAL

The subject of urban waste disposal is too large and complicated to be treated here in more than a superficial manner. Interested persons are referred to relevant literature on the subject (e.g., Flawn, 1970), and persons involved in planning waste-disposal facilities should seek the assistance of qualified geologists as well as the Pennsylvania Department of Environmental Resources.

In general, urban and industrial waste falls into two categories; solid and liquid. Solid wastes are usually treated either by incineration, which may contribute to air pollution, or by sanitary landfills in which waste accumulation is covered and compacted with a layer of earth to contain and isolate the fill. Proper sanitary landfills require careful site selection in order to meet three basic conditions: (1) the site should be above the ground-water table, (2) the permeability of the earth material should be sufficiently low to retard movement of contaminants, and (3) produced contaminants should not be able to reach the ground-water reservoir. Proper selection of a sanitary-landfill site requires careful preliminary geological and soils investigation.

Liquid-waste disposal involves wholesale dumping of untreated contaminants into the environment, which should not be tolerated, and

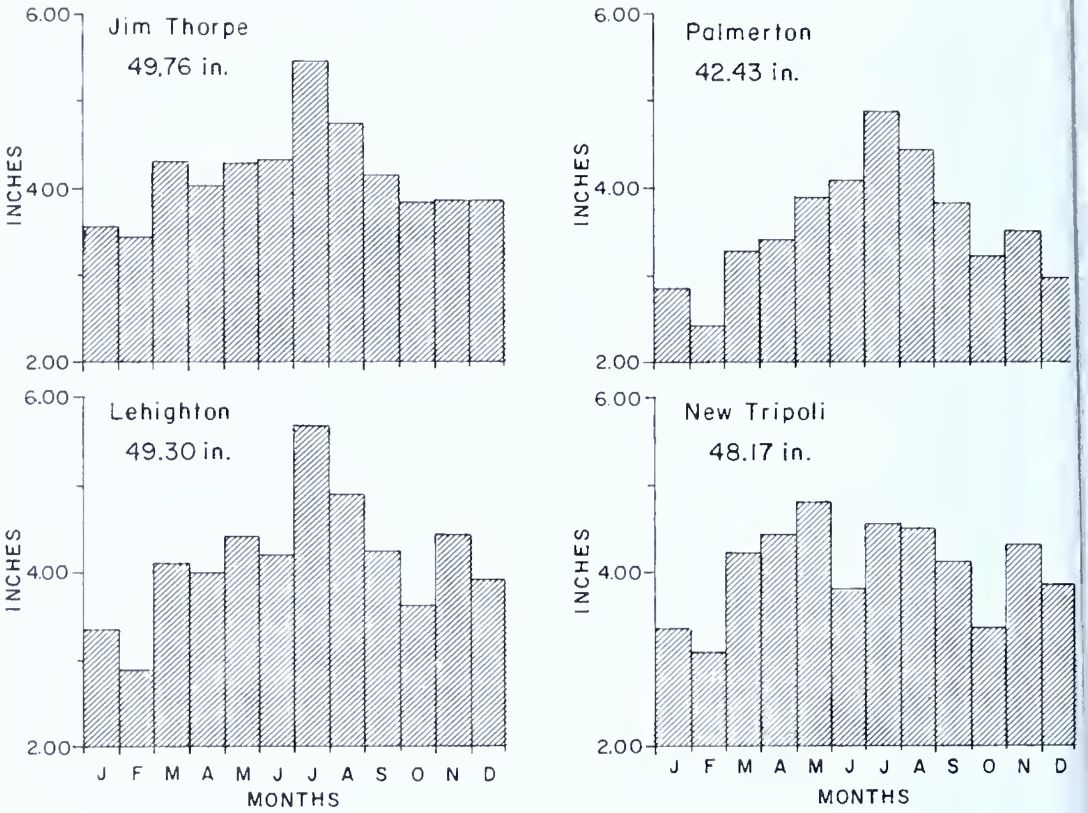

Figure 166. Mean monthly precipitation at four recording stations in or near the Lehighton-Palmerton-Jim Thorpe area. Mean annual precipitation indicated beneath name of recording station. Length of station record (in years): Jim Thorpe, 66; Lehighton, 45; Palmerton, 43; and New Tripoli, 22. Data from U.S. Department of Commerce (1964).

dumping of treated liquids into the environment, which should be done with discretion. Common practice is to put treated or partly treated liquids into a stream, such as the Lehigh River. However, these wastes often have a long-term harmful effect on the downstream character of the water body and alternate disposal methods should be considered (Rudd, 1972). A particularly valuable method of disposal that is feasible under special conditions is that of recharging the ground-water supply through spray irrigation with renovated sewage effluent (Parizek and others, 1967). Such disposal also has beneficial agricultural effects. Planning for such a system requires careful investigation of the soil and geologic conditions prior to installation (McGlade and others, 1972).

## SURFACE WATER

Information related to surface water in the mapped area is summarized in papers by Parker and others (1964) and McCarren and Keighton

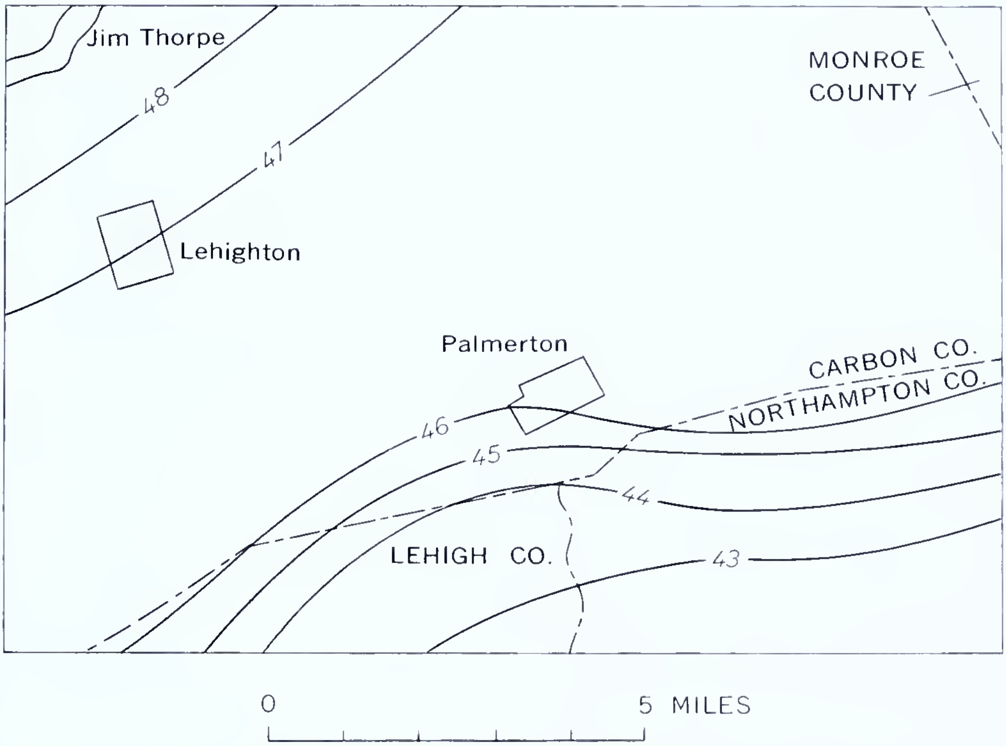

Figure 167. Map of the Lehighton and Palmerton quadrangles showing average annual precipitation, 1921–1950. From Parker and others (1964). Contours of average annual precipitation in inches.

(1969). The most recent studies of the hydrology south of Blue Mountain are by Wood and others (1972). Other information used in the following discussion is taken from various U.S. Geological Survey reports (U.S. Geol. Survey, 1942, 1943, 1944, 1945, 1946, 1947, 1949, 1950, 1951, 1952, 1953, 1954b, 1955, 1956, 1958a, 1958b, 1959, 1960a, 1960b, 1960c, 1961a, 1961b, 1962a, 1962b, 1963, 1964, 1965, and 1966) which present tabulations of yearly gaging station data.

All of the mapped area drains into the Lehigh River and three stream gaging stations within the area allow some analysis of sediment loss and water quantity and quality. These gaging stations are located north of Parryville, at Palmerton, and at Walnutport. Table 17 presents some basic data related to the surface water of the area and indicates the magnitude of stream flows recorded. Figure 170 shows the mean monthly discharge of water for the three gaged streams of the area. Of interest in this figure is the close correspondence of discharge characteristics between the three streams, the peak discharge during March and April and the secondary maximum discharge peak in December.

A comparison of Figure 170 with Figure 166 indicates that there is no relationship between peak rainfall (July and August) and peak dis-

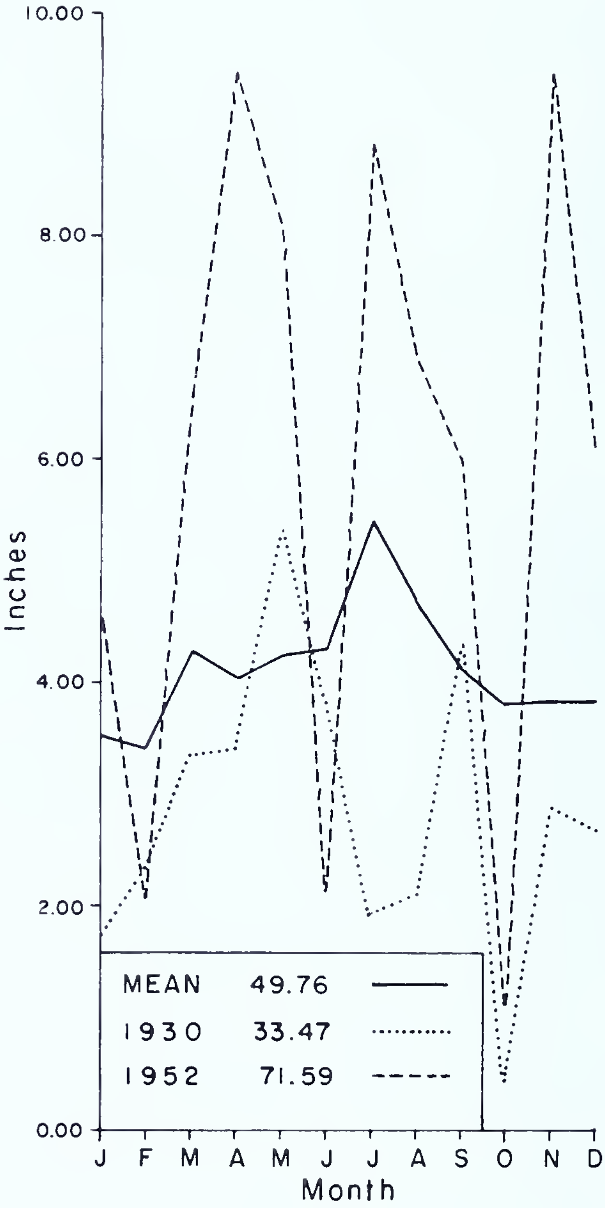

Figure 168. Monthly precipitation records at Jim Thorpe for the wettest (1952) and driest (1930) years on record for the period 1890–1959. Data from U.S. Department of Commerce (1964).

charge. Climatic data for the Pocono plateau, as typified in Table 16 (U.S. Dept. Commerce, 1964), indicate that most of the snowfall occurs from December through March and is distributed more or less evenly over this four-month period. Discharge and snowfall have a close relationship to temperature (Figure 169). During December, the first month of heavy snowfall, the mean temperature is above freezing, resulting in considerable melting, runoff, and increased discharge. While January

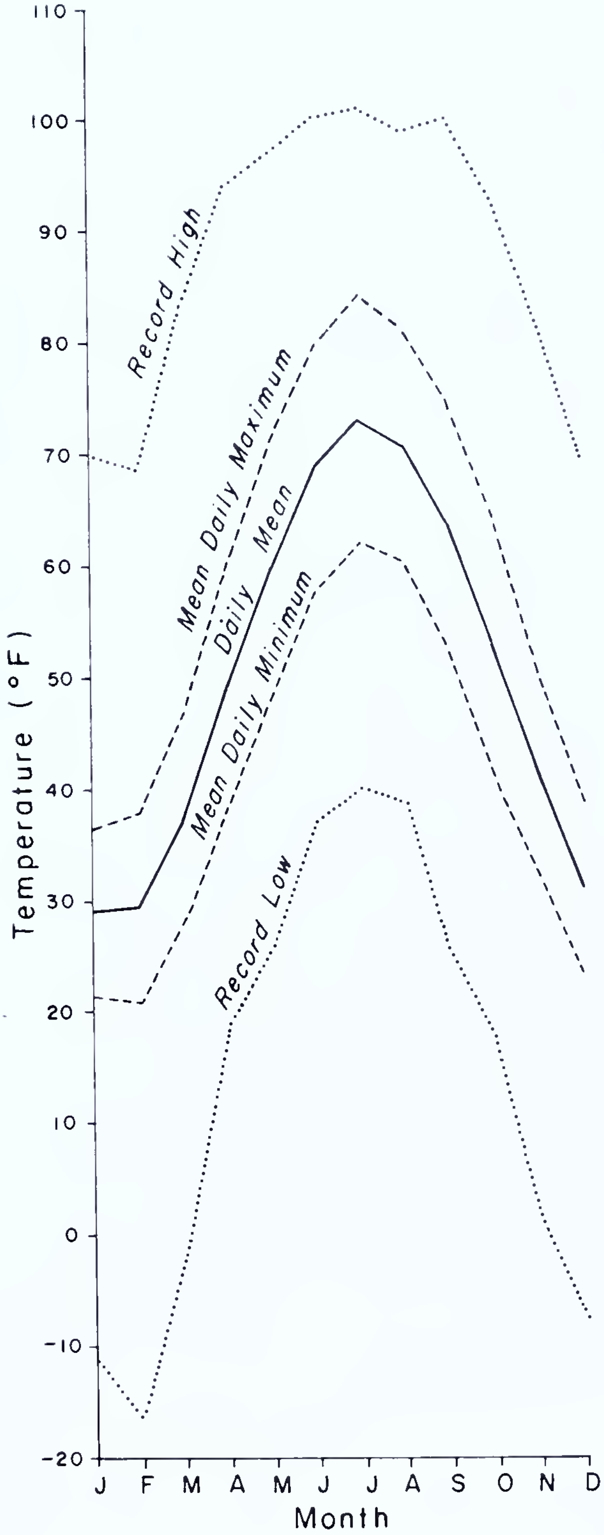

Figure 169. Temperature records for Palmerton based on 28-year record. Data from U.S. Department of Commerce (1964).

## Table 16. *Miscellaneous Climatic Data for the Lehighton-Palmerton Quadrangle Area*

(Data from U.S. Department of Commerce (1964), based on 10-year records for 1951–60)

Mean Number of Days with Precipitation ≥ 0.10 or ≥ 0.50 Inch

Jim Thorpe

| | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.10 | 5 | 7 | 7 | 9 | 7 | 6 | 7 | 7 | 7 | 7 | 6 | 5 | 80 |
| 0.50 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 34 |

Lehighton

| | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.10 | 5 | 6 | 9 | 8 | 7 | 6 | 7 | 8 | 7 | 7 | 6 | 7 | 83 |
| 0.50 | 2 | 3 | 3 | 4 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 2 | 37 |

Palmerton

| | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.10 | 5 | 6 | 8 | 8 | 7 | 6 | 7 | 7 | 6 | 6 | 6 | 5 | 77 |
| 0.50 | 2 | 3 | 2 | 3 | 3 | 2 | 4 | 4 | 3 | 3 | 3 | 2 | 34 |

New Tripoli

| | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.10 | 6 | 6 | 7 | 9 | 7 | 7 | 7 | 8 | 6 | 7 | 7 | 6 | 83 |
| 0.50 | 2 | 3 | 3 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 36 |

Average Snowfall in Inches (includes sleet and hail ) at Jim Thorpe for 58-Year Record ending 1952

| J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.9 | 10.6 | 6.9 | 1.3 | T | T | 0 | T | T | 0.1 | 2.3 | 7.4 | 39.5 |

Mean Number of Days at Palmerton with Temperature ≥ 90° or ≤ 32°

| | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 90° | 0 | 0 | 0 | + | 0 | 3 | 5 | 2 | 1 | 0 | 0 | 0 | 11 |
| 32° | 28 | 25 | 22 | 6 | 1 | 0 | 0 | 0 | 1 | 6 | 18 | 26 | 133 |

## Table 17. *Miscellaneous Surface Water Data for the Lehighton and Palmerton Quadrangles*

(Data from McCarren and Keighton, 1969)

| | | Gaging Station | |
|---|---|---|---|
| | Pohopoco Creek north of Parryville | Aquashicola Creek at Palmerton | Lehigh River at Walnutport |
| Drainage area (sq. mi.) | 109 | 76.7 | 889 |
| Average discharge (cfs) | 209 | 145 | 1,729 |
| Maximum discharge (cfs) | 5,300 (5/23/42) | 11,700 (7/10/45) | 77,800 (8/19/55) |
| Minimum discharge (cfs) | 13 (9/25/64) | 2.6 (9/12/57) | 57 (7/27/65) |
| Maximum flood height (ft.) | — | — | 20.6 (5/23/42) |

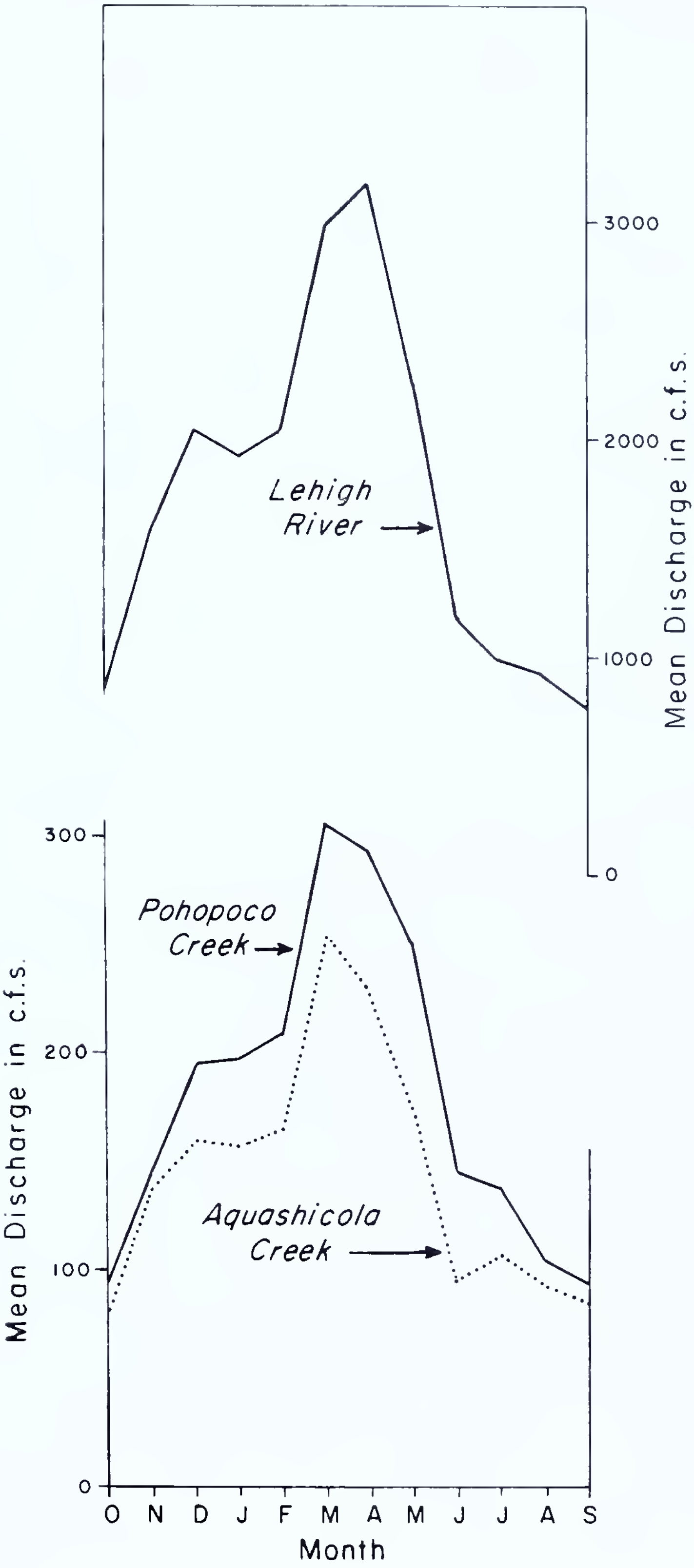

Figure 170. Mean monthly discharge of water in the Lehigh River, Pohopoco Creek, and Aquashicola Creek, Carbon County, Pennsylvania. Scale on right side applies to Lehigh River only. Scale on left applies to Pohopoco and Aquashicola Creeks. Monthly means based on 21-year record (1946–1966) for Lehigh River; 27-year record (1940–1966) for Pohopoco Creek; and a 26-year record (1939–1966) for Aquashicola Creek. Data from gaging station records at Parryville, Palmerton, and Walnutport.

and February are high snowfall months, they are also months with mean temperature below freezing and thus have a corresponding water retention. In March the mean temperature rises to well above freezing, which results in melting, runoff, and increased discharge in response to heavy snowfall.

Although the data in Figure 170 indicate that peak discharges on the Lehigh River normally occur in November or December, large discharges may occur at any time during the year. Table 17 shows that maximum known discharges for the three gaged streams in the area are not related in month or year and also did not occur in the months of normal peak discharge. Historically, one of the most extensive floods of the Lehigh River occurred on June 4 and 5, 1862. According to reports in Mathews and Hungerford (1884) rain started on the afternoon of June 3rd and fell heavily until 11:00 a.m. on June 5th. The resulting flood destroyed or damaged most of the Lehigh Canal structures between White Haven and Jim Thorpe and that section of the canal was never rebuilt. According to Morton (1946), this flood reached a height of 27 feet above a dam then in existence at Jim Thorpe (crest of dam estimated at 7 feet above present stream level). Morton (1946) also indicates that a more severe flood occurred in 1869 and that the most severe flood known occurred in 1841.

During July and August, 1969, the area experienced excessive rainfall and resultant flooding. Heavy rainfall fell throughout most of Carbon and Monroe Counties on July 28 and 29 and in parts of Carbon and Schuylkill Counties on August 1 and 2. Table 18 presents some data collected from several streams in the area following the July rains. Damage, if any, resulting from flooding of these streams is not known.

Intensive rainfall in the Jim Thorpe and Lehighton area on August 1 and 2, 1969, resulted in extensive flood damage to Jim Thorpe. Rainfall records in Jim Thorpe indicate that 11.65 inches fell in July—7.65 inches above normal. A moderate portion of this fell on July 28th when Mauch Chunk Creek came within one foot of overflowing its banks. In an already rain saturated area, rainfall on August 1 and 2 was as follows: August 1, 4:15 to 6:30 p.m.—1.60 inches; August 1, 8:15 p.m. to August 2, 7:00 a.m.—4.02 inches. Lehighton experienced 5.35 inches of rainfall between 8:00 p.m. on August 1 and 12:30 a.m. on August 2. The rainfall caused flooding of Mauch Chunk Creek and resulted in over $250,000 worth of damage in Jim Thorpe.

Extensive flooding in various parts of Carbon, Monroe, and Schuylkill Counties during late July and early August, 1969 caused a total of over $3.3 million damage. The area as a whole is subject to local or widespread intense rainfall during almost any time of the year.

Table 18. *Flood Height, Flow Velocity and Channel Width Data for Several Streams in the Mapped Area*

(Data collected by W. D. Sevon. Flood data collected on July 29, 1969; normal flow data on October 23, 1969)

| Stream | Channel width | | Height of flood flow above normal flow | Relative increase of flood surface velocity | Location of measurements |
|---|---|---|---|---|---|
| | Normal | Flood | | | |
| Borger Ck. | 8′ | 30′3″ | 2′1″ | 2.6× | North side bridge on road from Kunkletown to Little Gap. |
| Hunter Ck. | 6′ | 24′ | 3′3″ | 2.2× | West side bridge on private road at Little Gap Grange, Little Gap. |
| Buckwha Ck. | 39′ | 66′* | 6′8″ | 5.7× | East side bridge, covered bridge in Little Gap. |
| Aquashicola Ck. | 40′** | 40′* | 2′11″ | 2.1× | East side bridge, road from Little Gap to Danielsville. |
| Mill Ck. | 21′6″** | 21′6″* | 3′7″ | 2.8× | South side bridge at Aquashicola, on road to Bowmanstown. |
| Fireline Ck. | 2′ | 22′ | 1′10″ | 4.5× | North side bridge on Fireline Road, Bowmanstown, near Florences Bar. |
| Lizard Ck. | 66′** | 66′* | 4′7″ | 8.2× | West side bridge on road south from West Bowmans to Lizard Ck. Jct. |
| Nis Hollow Ck. | 6′ | 12′* | 1′ | 3.0× | North side bridge on road north from West Bowmans. |
| Mahoning Ck. | 42′ | 138′ | 3′6″ | 3.2× | East side, 9th St. bridge, Lehighton. |

* Width at bridge constriction; somewhat wider upstream.

** Full width flow at bridge; narrower upstream.

Recent construction of the Francis E. Walter Dam across the Lehigh River about 16 miles north of Jim Thorpe has reduced the severity of Lehigh River floods by impounding flood waters in the upper Lehigh River drainage basin. Controlled release of water from this dam during the intense rainfall period of 1969 prevented flood damage along the Lehigh River. However, some flooding may still be anticipated in the mapped area and construction on river floodplains is not recommended. The new Beltzville Dam across Pohopoco Creek will further reduce flood potential by controlling floodwaters in that stream.

Data are available which show the variation in suspended sediment and mean discharge for the period May, 1947 through March, 1953 at the Walnutport gaging station (U.S. Geol. Survey, 1950, 1951, 1952, 1953, 1954a, 1955, and 1956). The data indicate a close correspondence between discharge and suspended load. Of interest is Figure 171 which shows two examples of the normal flood-sediment-discharge relationship. In a flood of two or more days' duration, peak sediment load normally precedes peak discharge. This phenomenon presumably indicates that initial runoff and increased stream velocity, by virtue of their position in time, erode and transport more sediments than later peak flow because more material is available to the earlier flow.

The data reported in U.S. Geological Survey (1954a) indicate that under normal flow conditions the material composing the Lehigh River sediment load is mainly finer than coarse silt. No data are available for flood conditions or for other streams in the area.

Chemical analyses of water from the Lehigh River and several tributaries are presented in McCarren and Keighton (1969; Table 6).

Flood frequency and magnitude studies have been made for Aquashicola Creek by Reich (1969) and Figure 172 is a flood frequency and magnitude predictive curve modified from that report. This figure indicates that the mean flood will occur every 2.33 years and have a discharge of 2,480 cubic feet per second at the gaging station 1.25 miles upstream from the stream mouth. The mean flood discharge may normally be expected to deviate up to 2,081 cubic feet per second (standard deviation value) from the predicted discharge value. Figure 172 may be used to predict flood discharge values for other return periods (e.g., a flood with a discharge of about 4,600 cfs may be expected about every 10 years). Interested persons are referred to the report by Reich (1969) for further information on the original data, computation of the predictive curve, and other predictive curves.

## GROUND WATER

Ground water is part of a circulatory system known as the hydrologic cycle. In the hydrologic cycle, water falls to the ground as rain or snow

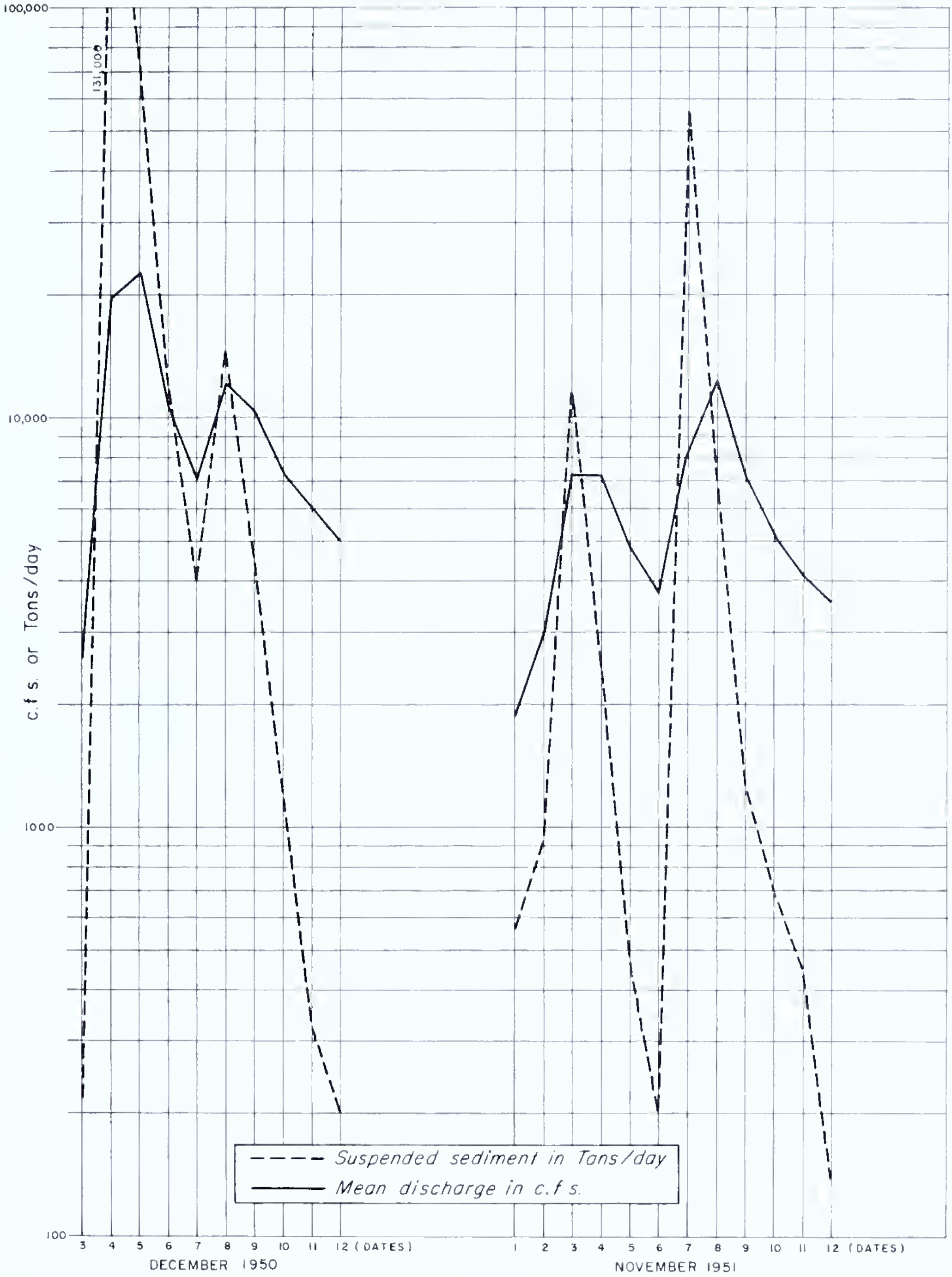

Figure 171. Examples of peak variations in suspended sediment and mean discharge for the Lehigh River at Walnutport, Pennsylvania. Note that peak sediment load generally precedes peak discharge. Data from U.S. Geol. Survey (1953, 1954a).

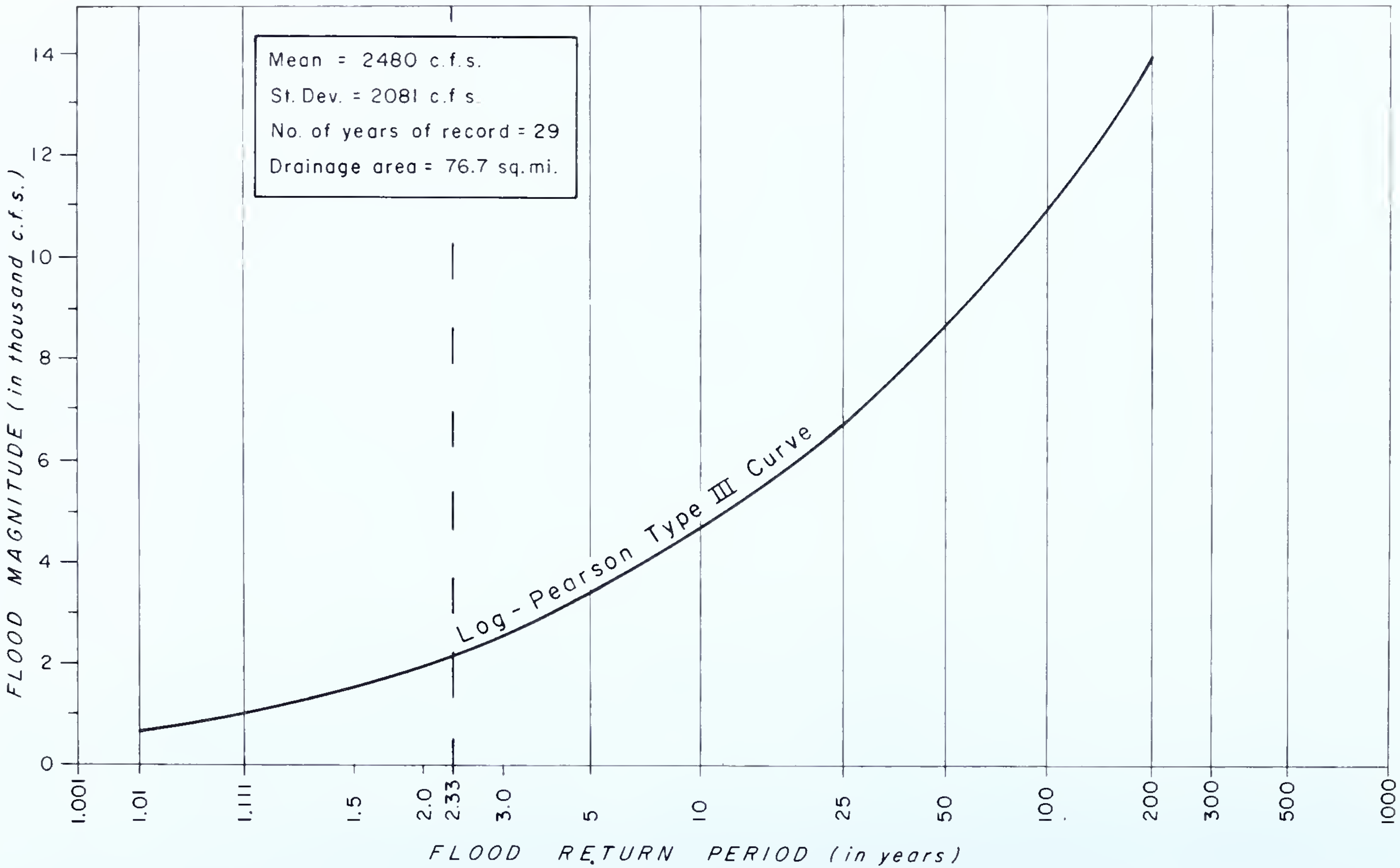

Figure 172. Flood frequency and magnitude predictive curve for Aquashicola Creek, Carbon County, Pennsylvania (modified from Reich, 1969, p. 51).

and either flows over the surface as runoff to streams or infiltrates into the ground following openings in the rock. Some of the infiltrating water is taken up by plants and put back into the air by transpiration, while some water is put back into the air by evaporation from streams and lakes. This water eventually falls as rain, thus repeating the cycle. The zone above the ground-water table contains variable amounts of water moving slowly downward, and wells drilled into this zone are usually dry. The zone below the ground-water table is saturated with water, and wells drilled into this zone usually will produce water. The ground-water table is irregular, generally conforms to the hills and valleys, and sometimes intersects the surface in valleys at streams. There is movement of ground water from higher to lower elevations within the saturated zone. Thus, effluent from a waste-disposal system at a hilltop would infiltrate downward to the ground-water table, move downslope, and might contaminate a well intake in the valley; such situations are to be avoided.

Some ground-water information for the mapped area is presented by Lohman (1937, p. 70-87), Hall (1934), Poth (1972), and Wood and others (1972), and data for more recently drilled wells are presented in Table 19. These data are listed in township groupings and organized stratigraphically in order of certainty of identification of the producing horizon. Table 20 summarizes the data of Table 19 for four specific rock units within the mapped area. The data in Table 20 were analyzed in a variety of ways (e.g., township versus unit; certainty of unit versus township; total wells versus area), but only the total wells versus unit and total wells versus area data are reported, since no significant differences were noted between the results of the several analytical approaches.

Table 20 indicates a similarity in ground-water occurrence between the various source rocks. The deeper average depth of well for the Trimmers Rock Formation is a reflection of a number of wells drilled in the Forest Inn area on a topographically high position.

The data in Tables 19 and 20 indicate that moderate quantities of water are available from bedrock throughout the area. No data are available on water from several of the rock units (e.g., Marcellus and Pocono Formations, several members of the Catskill Formation), but these units probably have about the same potential as those units for which data exist. Although the range is large, wells drilled in any formation in the area need generally be less than 150 feet deep and the static water level will generally be more than 40 feet deep. Artesian conditions are uncommon and known mainly in East Jim Thorpe where the structure of the bedrock (syncline) is ideally suited for artesian flow. In the remainder of the area there is not sufficient structural relief to develop an adequate head for artesian flow. Although water yield varies con-

Table 19. *Records of Water Wells Drilled in the Lehighton-Palmerton-Jim Thorpe Area between 1963 and 1969*

(Compiled from records on file at the Pennsylvania Geological Survey, Harrisburg)

| Map unit[1] | Lithology[2] | Surficial material[2] | Depth to bedrock (ft) | Depth of well (ft) | Depth to water-bearing zones (ft) | Yield (gpm) | Static water level (ft) | Date drilled | Location |
|---|---|---|---|---|---|---|---|---|---|
| *East Penn Township* | | | | | | | | | |
| Sb | red shale | clay and boulders | 94 | 231 | 124/205 | 15 | 125 | 8/31/68 | Lizard Creek Junction |
| Dm | slate | clay and loose formation | 23 | 122 | 109/ | 25 | 20 | 7/ 5/67 | Ashfield |
| Dm | slate | — | 40 | 230 | 218/226 | 10 | — | | Ashfield |
| Dm | slate | clay and surface formation | 30 | 140 | 100/138 | 20 | 30 | 6/66 | Ashfield |
| Dm | slate | surface formation clay | 36 | 74 | 55/66 | 40 | 15 | 6/66 | Ashfield |
| Dm? | shale | loam | 96 | 156 | 140/148 | 10 | 50 | 11/ 4/68 | |
| Dm? | shale | clay and surface formation | 38 | 245 | 164/240 | 12 | 70 | 5/17/67 | |
| Dm? | slate | clay | 57 | 332 | 80/220 | 10 | 30 | 9/66 | |
| Dm? | shale | boulders, clay, and shale | 35 | 77 | 62/75 | 20 | 30 | 5/12/68 | Andreas area |
| Dcw? | red rock | clay | 135 | 146 | 144/ | 15 | 36 | 4/13/68 | |
| ? | sandy rock | loam | 36 | 251 | 225/243 | 10 | 107 | 9/ 7/68 | |
| ? | shale and sandstone | clay and surface formation | 37 | 283 | 90/275 | 15 | 62 | 5/20/67 | |
| ? | sandstone | clay, sand, and soft formation | 76 | 356 | 120/153 | 36 | 60 | 2/21/67 | |
| ? | blue rock | — | | 400 | 112/375 | 5 | 15 | 7/18/67 | South of Ashfield |
| ? | blue rock | clay and gravel | 45 | 82 | 48/82 | 15 | 38 | | |
| *Franklin Township* | | | | | | | | | |
| Do? | limestone | clay surface formation | 58 | 405 | 372/390 | 11 | 100 | 6/66 | Bridge St., Weissport |
| Dm | slate | surface formation and clay | 43 | 82 | 60/78 | 28 | 48 | 7/29/66 | East Weissport |
| Dm | slate | clay and soft formation | 47 | 128 | 87/100 | 20 | — | — | Big Creek |
| Dm | slate | soft formation | 15 | 120 | 90/105 | 20 | 25 | 8/21/67 | Beltzville Dam area |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Dm | slate | clay and shale | 32 | 153 | 95/125 | 22 | — | | South of U.S. Route 209 in east Weissport area |
| Dm | slate | loose shale | 50 | 152 | 60/90 | 6 | 44 | | South of U.S. Route 209 between Weissport and Harrity |
| Dm | slate | clay and shale | 33 | 110 | 75/90 | 12 | 35 | 11/ 9/66 | Near school at North Weissport |
| Dm | slate | clay and shale | 38 | 97 | 78/90 | 30 | 50 | 12/15/66 | Halfway between North Weissport and Indian Hill |
| Dm | shale | clay and shale | 15 | 80 | 35/65 | 40 | 12 | 10/ 2/66 | Near cemetery in North Weissport |
| Dm | hard gray rock | clay and shale | 35 | 102 | 65/89 | 30 | 45 | 3/10/37 | East of fish hatchery on Sawmill Run |
| Dm | shale | clay and shale | 45 | 113 | 100/108 | 30 | 50 | 2/21/67 | Between North Weissport and Indian Hill |
| Dm | limestone | clay and shale | 26 | 100 | 37/85 | 3 | 20 | 3/14/67 | Harrity |
| Dm | shale | fill | 10 | 94 | 55/85 | 30 | 4 | 9/14/67 | Between Mahoning Valley Interchange and Pohopoco Creek |
| Dm | shale | shale | 17 | 110 | 30/85 | 15 | 25 | 10/16/67 | 0.3 mile west of Harrity on T 436 |
| Dm | shale | overburden | 70 | 143 | 85/130 | 15 | 65 | 7/ 2/68 | North of East Weissport |
| Dm | shale | clay and shale | 20 | 79 | 50/60 | 40 | 12 | 9/19/67 | Between Weissport and East Weissport |
| Dm | slate | clay and shale | 40 | 165 | 65/115 | 30 | 50 | 4/15/68 | North Weissport area |
| Dm | shale | overburden | 28 | 85 | 30/69 | 30 | 30 | 7/26/68 | 1 mile east of Harrity on T 397 |
| Dm | slate | shale | 48 | 120 | 85/115 | 14 | 28 | 10/25/68 | East Weissport |
| Dm | shale | clay and boulders | 90 | 320 | 196/209 | 16 | — | — | Beltzville Dam site |
| Dm | slate | clay and soft formation | 40 | 144 | 118/136 | 40 | 18 | 10/22/66 | 230 White Street, Weissport |

Table 19. *(Continued)*

| Map unit[1] | Lithology[2] | Surficial material[2] | Depth to bedrock (ft) | Depth of well (ft) | Depth to water-bearing zones (ft) | Yield (gpm) | Static water level (ft) | Date drilled | Location |
|---|---|---|---|---|---|---|---|---|---|
| Dm | slate | loose formation | 40 | 111 | 52/86 | 15 | 35 | 8/25/67 | R. D. 4, Lehighton |
| Dm | limestone | loose rock | 58 | 305 | 189/205 | 11 | 180 | 10/ 1/68 | Union Hill |
| Dm | shale | overburden | 20 | 100 | 65/90 | 8 | 20 | 8/19/68 | 0.2 mile west of intersection of T 512 and U.S. Route 209 |
| Dm | slate | shale | 30 | 122 | 35/90 | 11 | 25 | 6/30/66 | East of Harrity |
| Dm | shale | river bottom | 16 | 100 | 37/97 | 16 | 13 | 8/ 6/66 | |
| Dm | shale | clay and shale | 50 | 105 | 88/98 | 40 | 74 | 9/26/66 | Pine Run area |
| Dm? | slate | surface formation | 17 | 122 | 95/115 | 45 | 85 | 12/23/66 | 123 Allen, Weissport |
| Dm? | slate | clay and soft formation | 57 | 146 | 90/133 | 50 | 45 | 2/14/66 | R. D. 3, Lehighton |
| Dm? | slate | clay and soft formation | 32 | 152 | 117/147 | 12 | 37 | 9/13/66 | R. D. 4, Lehighton |
| Dm? | slate | clay and soft formation | 36 | 250 | 216/245 | 14 | 120 | 4/ 6/67 | R. D. 4, Lehighton |
| Dm? | slate | clay and soft formation | 57 | 135 | 70/125 | 24 | 20 | 4/ 7/67 | R. D. 4, Lehighton |
| Dm? | slate | soft shale | 36 | 120 | 74/98 | 31 | 20 | 8/28/67 | R. D. 4, Lehighton |
| Dm? | blue rock | shale | 65 | 192 | 100/165 | 9 | 60 | 9/20/66 | R. D. 3, Lehighton |
| Dm? | blue rock | shale | 21 | 120 | 50/100 | 15 | 8 | 9/20/68 | |
| Dm? | slate | clay and surface formation | 54 | 218 | 100/180 | 13 | 80 | 6/66 | |
| Dm? | shale | sand and shale | 16 | 60 | 48/54 | 30 | 10 | 7/29/66 | |
| Dm-Dtr | slate | clay and surface formation | 56 | 475 | 280/465 | 12 | 200 | 5/67 | 0.5 mile south of U.S. Route 209 on Pa. Route 248 |
| Dtr | brown and blue sandstone | overburden | 55 | 103 | 55/90 | 30 | 30 | 5/ 2/68 | East of Forest Inn along U.S. Route 209 |
| Dtr | shale | soft shale | 35 | 268 | 122/260 | 13 | 100 | 1/ 9/69 | Parryville |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Dtr | slate | overburden shale | 39 | 166 | 85/155 | 10 | 65 | 8/15/68 | Southeast of Mahoning Valley Interchange |
| Dtr | limestone | clay and soft formation | 40 | 248 | 178/246 | 10 | 75 | 11/13/67 | Parryville |
| Dtr | shale and sandstone | soft shale | 40 | 203 | 107/196 | 10 | 100 | 8/66 | Parryville |
| Dtr? | blue rock | shale | 38 | 209 | 75/137 | 15 | 56 | 11/3/66 | |
| Dtr? | dark slate rock | clay and shale | 30 | 100 | 65/90 | 35 | 25 | 4/8/67 | 0.5 mile south of Walcksville |
| Dtr? | slate | clay and surface formation | 39 | 202 | 68/173 | 12 | 50 | 7/66 | Parryville |
| Dtr? | limestone | shale | 18 | 128 | 50/115 | 10 | 25 | 8/29/66 | Indian Hills? |
| Dtr? | green and blue rock | clay, sand, and boulders | 25 | 48 | 27/35 | 15 | 6 | 8/23/66 | Indian Hills? |
| Dcw | red shale and sandstone | | 36 | 265 | 115/212 | 30 | 58 | 5/13/68 | |
| Dcw | red sandstone and shale | clay boulders | 16 | 100 | 55/80 | 20 | 35 | 11/4/68 | Indian Hills, 1 mile southwest of Walcksville |
| Dcw | green sandstone and red shale | shale | 17 | 168 | 40/108 | 8 | 40 | 10/15/66 | Parryville |
| Dcbr | sandstone | overburden | 16 | 105 | 50/ | 30 | 50 | 2/19/68 | 1 mile north of intersection of T 432 and 13011 |
| Dclr | shale | clay and boulders | 40 | 118 | 103/110 | 30 | 68 | 7/15/66 | 1 mile east of Walcksville |
| ? | shale and conglomerate | clay surface and formation | 22 | 131 | 90/127 | 30 | 50 | 6/66 | Between Parryville and Bowmanstown |
| ? | sandstone | clay and soft formation | 37 | 202 | 100/170 | 27 | 40 | 2/16/67 | R. D. 3, Lehighton |
| ? | blue rock | hard shale | 15 | 106 | 54/75 | 20 | 14 | 6/14/67 | ? |

## Table 19. *(Continued)*

| Map unit[1] | Lithology[2] | Surficial material[2] | Depth to bedrock (ft) | Depth of well (ft) | Depth to water-bearing zones (ft) | Yield (gpm) | Static water level (ft) | Date drilled | Location |
|---|---|---|---|---|---|---|---|---|---|
| *Lower Towamensing Township* | | | | | | | | | |
| Dm | slate | — | 59 | 90 | 80/87 | 25 | 5 | 6/12/68 | Area north of Aquashicola |
| Dm | slate | — | 31 | 155 | 96/127 | 14 | 90 | 6/12/68 | North of Palmerton |
| Dm | shale | clay and boulders | 30 | 100 | 40/85 | 20 | 3 | 5/19/67 | 2 miles east of A1461 on 13014 |
| Dm | shale | clay and boulders; broken shale | 35 | 138 | 59/117 | 15 | 25 | 12/26/68 | 0.3 mile east on 13014 from intersection with 13046 |
| Dm | slate | clay and soft formation | 37 | 122 | 90/107 | 20 | 10 | 3/29/67 | Fireline Road |
| Dm | shale | overburden and shale | 32 | 141 | 55/130 | 9 | — | — | 0.3 mile east on 13014 from intersection with 13046 |
| Dm? | slate | surface formation clay | 58 | 218 | 72/170 | 12 | 40 | 7/ 7/66 | Fireline Road east of Palmerton |
| Dm? | slate | surface | 37 | 110 | 82/90 | 10 | 38 | 8/23/66 | |
| Dm? | shale | surface clay; soft shale | 39 | 152 | 90/146 | 12 | 60 | 8/66 | |
| Dm? | slate | overburden | 8 | 112 | 62/104 | 18 | 20 | 2/68 | |
| Dm? | slate | clay and surface formation | 37 | 122 | 90/107 | 20 | 10 | 3/29/67 | |
| Dm? | blue rock | — | 136? | 190 | 154/168 | 80 | 120 | 5/13/68 | Fireline Road |
| Dm? | slate | clay and surface formation | 37 | 111 | 47/101 | 24 | 10 | 4/ 4/67 | Fireline Road |
| Dcw | red shale | loose red shale | 13 | 92 | 40/52 | 15 | 35 | 7/14/66 | Fireline Road northeast of Bowmanstown |
| Dcw? | shale | — | 22 | 65 | 40/62 | 30 | 10 | 7/25/66 | Main Street, Parryville |
| Dcw? | red rock | — | 34 | 110 | 87/106 | 30 | 32 | 6/13/68 | Northeast of Aquashi- |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ? | conglomerate | clay and surface formation | 54 | 188 | 135/146 | 12 | 60 | 8/66 | |
| ? | sandstone | clay and soft formation | 37 | 265 | 150/260 | 15 | 30 | 6/67 | |
| ? | blue rock and "quartzed" | shale | 21 | 150 | 84/124 | 10 | 65 | 10/26/68 | |
| ? | sandstone | clay, sand, and boulders | 71 | 96 | 92/ | 8 | 20 | 12/28/67 | Between Aquashicola and Little Gap |
| ? | sandstone | clay, sand, and boulders | 80 | 200 | 160/172 | 100 | 72 | 9/23/67 | 380 Lehigh Avenue, Palmerton |
| ? | sandstone | clay, sand, and boulders | 95 | 218 | 180/214 | 14 | 100 | 9/20/67 | 402 Lehigh Avenue, Palmerton |
| *Mahoning Township* | | | | | | | | | |
| Dm | shale | no data | 1 | 80 | 30/60 | 18 | 20 | 7/ 9/68 | 1.2 mile west on 13008 (Pa. Route 902) from intersection with U.S. Route 209 |
| Dm | slate | soft shale | 38 | 157 | 51/130 | 15 | 60 | 3/26/68 | R. D. 1, Lehighton |
| Dm | slate | clay and soft formation | 47 | 128 | 87/100 | 20 | 30 | 7/18/66 | Big Creek |
| Dm | blue rock | gravel and shale | 8 | 71 | 50/60 | 30 | 1 | 6/15/66 | Pa. Route 902, R. D. 1, Lehighton |
| Dm | slate | overburden | 48 | 170 | 90/148 | 150 | 90 | 6/19/68 | Along Pa. Route 443, west of Lehighton |
| Dm | shale | shale and clay | 30 | 98 | 80/94 | 25 | — | — | Lehighton, west of old U.S. Route 209 |
| Dm | slate | clay and surface formation | 37 | 74 | 51/68 | 15 | 35 | 7/66 | 316 North 7th, Lehighton |
| Dm? | slate | clay boulders | 45 | 66 | 47/56 | 40 | 14 | 9/19/66 | R. D. 1, Lehighton |
| Dm? | slate | boulders, clay, black clay | 53 | 107 | 78/90 | 25 | 68 | 9/10/66 | R. D. 1, Lehighton |
| Dm? | slate | fill and shale | 16 | 78 | 45/65 | 16 | 13 | — | R. D. 1, Lehighton |
| Dm? | slate | sand and boulders | 30 | 85 | 54/72 | 20 | 17 | 6/ 4/68 | R. D. 1, Lehighton |
| Dm? | slate | soft shale | 12 | 108 | 35/50 | 20 | 18 | 8/10/66 | R. D. 1, Lehighton |

Table 19. *(Continued)*

| Map unit[1] | Lithology[2] | Surficial material[2] | Depth to bedrock (ft) | Depth of well (ft) | Depth to water-bearing zones (ft) | Yield (gpm) | Static water level (ft) | Date drilled | Location |
|---|---|---|---|---|---|---|---|---|---|
| Dm? | slate | soft shale | 37 | 200 | 60/104 | 8 | 32 | 7/20/66 | R. D. 1, Lehighton |
| Dm? | shale | boulders, shale | 36 | 131 | 75/108 | 20 | 28 | 9/ 4/68 | |
| Dm? | shale | clay boulders, black clay | 55 | 132 | 75/83 | 20 | 43 | 8/24/63 | |
| Dm? | slate | clay and surface formation | 37 | 97 | 53/76 | 27 | 4 | 6/66 | R. D. 1, Lehighton |
| Dm? | shale | shale | 18 | 76 | 58/68 | 20 | 18 | 4/24/67 | R. D. 1, Lehighton |
| Dm? | blue rock | boulders | 14 | 66 | 50/55 | 20 | 10 | 7/26/68 | R. D. 2, Lehighton |
| Dm? | slate | clay and boulders | 35 | 139 | 66/98 | 20 | 20 | 8/25/67 | R. D. 1, Lehighton |
| Dm? | slate | clay, sand, boulders, and black clay | 38 | 139 | 98/104 | 30 | 20 | — | R. D. 1, Lehighton |
| Dm? | blue rock | shale | 35 | 160 | 75/130 | 28 | 30 | 2/31/67 | R. D. 2, Lehighton |
| Dcw | red sandstone | | 70 | 194 | 110/190 | 14 | 85 | 6/18/64 | Normal Square and Andreas |
| Dcw? | red shale | boulders, soft shale | 45 | 100 | 91/96 | 20 | 74 | 11/ 5/66 | R. D. 2, Lehighton |
| Dcw? | red rock | loam, broken shale | 20 | 78 | 36/55 | 20 | 8 | 9/ 4/66 | R. D. 1, Lehighton |
| Dclr | red shale | boulders and red clay | 70 | 102 | 80/ | 30 | 55 | 7/ 4/67 | R. D. 1, Lehighton |
| Dclr | sandstone | surface and loose formation | 34 | 155 | 144/149 | 12 | 68 | 1/23/69 | 33 Pine Street, Packerton |
| Dclr | red sandstone | clay | 10 | 140 | 65/110 | 20 | 65 | 12/12/68 | 0.1 mile west of U.S. Route 209 on 13009 |
| Dclr | red shale | overburden | 55 | 125 | 90/ | 25 | 85 | 2/ 1/68 | 0.1 mile west on T 389 from intersection with T 421 |
| Dclr | red shale | red clay | 20 | 130 | 110/ | 15 | 100 | 8/12/67 | 136 Mauch Chunk Street, Packerton |
| Dclr | blue-green sandstone | clay and boulders | 75 | 97 | 80/ | 30 | 55 | 7/ 1/67 | 0.5 mile west of T 389 from intersection with T 421 |
| Dclr? | sandstone | overburden | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ? | sandstone | broken rock | 10 | 130 | 81/129 | 20 | 0 | 8/22/66 | R. D. 1, Lehighton |
| ? | blue rock | clay, soft shale | 40 | 62 | 46/60 | 30 | 4 | 6/23/68 | R. D. 2, Lehighton |
| ? | blue rock | loam, shale | 19 | 86 | 32/36 | 40 | 11 | 7/30/66 | R. D. 1, Lehighton |
| ? | blue rock | broken shale | 20 | 38 | 37/ | 30 | 10 | 7/18/66 | R. D. 1, Lehighton |
| ? | sandstone | clay and boulders | 64 | 156 | 112/151 | 30 | 30 | 6/29/67 | R. D. 2, Lehighton |
| | no data | fill, clay, soft formation | 57 | 140 | 85/137 | 20 | 60 | 7/14/67 | Beaverdam Run |
| ? | quartzite | shale | 37 | 132 | 48/75 | 10 | 33 | 7/28/67 | R. D. 1, Lehighton |
| ? | quartzite | loam | 4 | 82 | 24/82 | 15 | 0 | 7/27/67 | R. D. 2, Lehighton |
| *Mauch Chunk Township* | | | | | | | | | |
| Mmc? | red shale and sandstone | boulders | 52 | 153 | 132/145 | 15 | 95 | 9/12/68 | 10th Street, Jim Thorpe |
| Mmc? | red rock | red overburden | 20 | 170 | 130/165 | 12 | 60 | 4/24/68 | Side road off Pa. Route 903 |
| *Towamensing Township* | | | | | | | | | |
| Dm | shale | overburden | 42 | 122 | 60/100 | 15 | 40 | 9/23/68 | Along T 478 north of Trachsville |
| Dm? | limestone | clay and shale | 74 | 160 | 90/145 | 20 | 60 | 7/12/67 | 1.0 mile north on 13012 from intersection with U.S. Route 209 |
| Dtr | sandstone | clay and soft formation | 41 | 370 | 337/350 | 12 | 70 | 9/20/66 | Between Forest Inn and Beltzville along U.S. Route 209 |
| Dtr? | slate | | 19 | 134 | 85/110 | 16 | 74 | 7/28/68 | New Forest Inn |
| Dtr? | sandstone | clay and soft formation | 40 | 200 | 156/195 | 15 | 75 | 10/31/67 | Along U.S. Route 209 near Forest Inn |
| Dtr? | shale | clay and soft formation | 37 | 200 | 97/196 | 8 | 90 | 11/22/67 | North side U.S. Route 209 between Forest Inn and Trachsville |

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[1] Line under map unit indicates positive identification; no line under map unit indicates probable identification; question mark after map unit indicates possible identification; question mark alone indicates identification unknown.

[2] Descriptions are given in drillers' terminology.

Table 20. *Summary of Water-Well Data Presented in Table 19 for the Lehighton and Palmerton 7½-Minute Quadrangles*

| Formation or member | Map symbol | Number of wells | Average* Depth to bedrock (ft) | Average* Depth of well (ft) | Average* Yield (gpm) | Average* Static water level (ft) |
|---|---|---|---|---|---|---|
| Mahantango | Dmh | 80 | 38<br>(1–136) | 133<br>(60–332) | 23<br>(3–150) | 37<br>(1–180) |
| Trimmers Rock | Dtr | 15 | 37<br>(18–56) | 204<br>(48–475) | 14<br>(8–35) | 71<br>(6–200) |
| Long Run | Dclr | 8 | 44<br>(10–75) | 126<br>(97–155) | 22<br>(12–30) | 76<br>(55–112) |
| Walcksville | Dcw | 10 | 41<br>(13–135) | 132<br>(65–265) | 20<br>(8–30) | 41<br>(8–85) |
| All other rock units | | 29 | 44<br>(4–95) | 175<br>(82–405) | 22<br>(5–100) | 48<br>(0–125) |
| Total for the area | | 142 | 40 | 150 | 22 | 46 |

*Values in parentheses indicate ranges.

siderably, the average well can be expected to yield about 22 gallons of good quality water per minute. Analyses of water from the wells in Table 19 are not available, but some chemical analysis data for public water supply wells are presented in Table 22.

Ground-water conditions, an inventory of water wells, and the quality of water in the Martinsburg Formation south of Blue Mountain are discussed by Poth (1972) and Wood and others (1972). According to these authors the yields of nondomestic water wells average 144 gpm in Lehigh County and 122 gpm in Northampton County in the Pen Argyl Member. Yields are highest near Blue Mountain because of unconsolidated material that acts as a reservoir overlying the bedrock. Yields in the Ramseyburg Member average 25 gpm in Lehigh County and about 30 gpm in Northampton County in nondomestic wells. Yields in domestic wells are considerably less than in nondomestic wells.

## Springs

The occurrence of springs was not specifically recorded during mapping. However, several springs occur in the topographic trough of the Weir Mountain syncline (bounded on the north by the ridge immediately south of Pohopoco Creek and on the south by the first ridge north of Stony Ridge). Permeable sandstones overlying impermeable red shales in the Walcksville Member combined with bedding dip create an environment favorable to the development of springs.

## PUBLIC WATER SUPPLY

The boroughs of Jim Thorpe, Lehighton, Bowmanstown, and Palmerton are served by public water supplies. Basic data related to these supplies are presented in Table 21 and chemical analyses of various waters are presented in Table 22. More complete data are on file at the Pennsylvania Department of Environmental Resources, Harrisburg, Pennsylvania. In 1970, the existing public water supplies were adequately serving the needs of their consumers and proposed expansion programs of the various water-supply concerns indicate growth calculated to meet and stay ahead of expected demand. An expansion program for the city of Palmerton proposes extraction of Pohopoco Creek water at Parryville, piping to Palmerton, and distribution following treatment. Two analyses (samples 6 and 7, Table 22) of raw Pohopoco Creek water at Parryville indicate that treatment is necessary before the water is suitable for human consumption.

Private and commercial water demand in the mapped area will probably continue to grow at a slow rate and thus not strain the ability of existing public water supplies to keep pace with demand. However, future development of water supply may result mainly from wells since there are few good sites in the area for impounding reservoirs. Some streams in the dissected center of the Weir Mountain syncline (Plate 1) are probably suitable for impoundment, but the high population density makes the sites undesirable. Good water supplies occur in numerous tributaries to the Lehigh River in the unpopulated area north of Jim Thorpe, but transport of the water to Jim Thorpe or places further south would be costly and probably feasible only as a result of greatly increased demand.

Public water supply for the borough of Slatington is obtained from springs and four wells with a total yield of 1.1 mgd (Wood and others, 1972). According to these authors, between 5 and 10 additional wells in the Martinsburg Formation would satisfy the borough's anticipated needs by the year 2020. The Lehigh River might be an alternative source, but the water of the river has a low pH and may be corrosive and special treatment may be required.

## EARTHQUAKES

The mapped area is in the western part of a region of considerable but moderate earthquake activity in which "Earthquakes occur throughout the region and the axis of principal activity roughly parallels the coast" (Eppley, 1965, p. 19). Although a few minor earthquakes have had epicenters in Wilkes-Barre, Allentown, Philadelphia, Lehigh Valley,

Table 21. *Public Water Supply Data for the Lehighton-Palmerton Area*

(Data from Pennsylvania Department of Environmental Resources)

| Borough or development | Approximate population served | Average yield per day (mgd) | Maximum yield per day (mgd) | Water treated? | Source of supply* | Chemical analyses (Table 22) |
|---|---|---|---|---|---|---|
| Jim Thorpe | 6,500 | 0.7 | 1.0 | Yes | c,s,w | 1,2 |
| Lehighton | 6,500 | 1.2 | 1.6 | Yes | c,w | 3,4,5 |
| Bowmanstown | 900 | .09 | — | Yes | s,w | 8,9 |
| Meadow Crest Manor | 40 | .002 | .0036 | No | w | 10 |
| Palmerton | 6,000 | .55 | .72 | Yes | w | 11 |

* c—creek or creek filled impounding reservoir
s—spring
w—well

## Table 22. *Chemical Analyses of Waters Used in Public Supplies in the Lehighton-Palmerton Quadrangle Area*

(Data from Pennsylvania Department of Environmental Resources)

| Sample | Collection date | Color | Odor | Turbidity | pH | Silica ($SiO_2$) | Total iron | Calcium (Ca) | Magnesium (Mg) | Sulfate ($SO_4$) | Chloride (Cl) | Nitrite ($NO_2$) | Nitrate ($NO_3$) | Free $CO_2$ | Total solids | Hardness | Alkalinity | Ammonia | Albuminoid | Coliform group/100 ml | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3/6/67 | 0 | 0 | 5 | 7.5 | | 0.1 | | | | 4 | 0.000 | 0.2 | | | 46 | | | | | Jim Thorpe: treated water |
| 2 | 2/5/68 | 5 | 331 | 5– | 7.5 | | .2 | | | | 8 | .000 | .1 | | | 24 | | | | | Jim Thorpe: treated water |
| 3 | 6/6/68 | 0 | 100 | 5– | 7.0 | | .4 | | | | 3 | .004 | .2 | | | 22 | | | | | Lehighton: treated water |
| 4 | 3/15/65 | | 0 | 20 | 6.3 | 2.8 | | 3.2 | 1.6 | 4 | 10 | | | 15 | 39 | 16 | 17 | | | | Lehighton: raw water from well #2 |
| 5 | 3/15/65 | | 0 | 5 | 6.1 | 3.1 | | 3.8 | 2.1 | 3 | 11 | | | 36 | 28 | 18 | 19 | | | | Lehighton: raw water from well #3 |
| 6 | 10/25/67 | 15 | 100 | 5 | 7.4 | | .6 | | | | 5 | .010 | .4 | | 58 | 56 | 15 | 0.02 | 0.034 | 2,400 | Pohopoco Creek at Parryville: raw water |
| 7 | 11/15/67 | 10 | 100 | 5 | 6.3 | | .2 | | | | 6 | .010 | .4 | | 74 | 34 | 16 | .006 | .032 | 790 | Pohopoco Creek at Parryville: raw water |
| 8 | 8/21/68 | 0 | 100 | 0 | 7.7 | | .2 | | | | 0 | .000 | .2 | | | 26 | | | | | Bowmanstown: treated water |
| 9 | | 5 | 0 | 0 | 6.8 | | .3 | 1.6 | 2.5 | 5 | 1 | .000 | .000 | | 42 | 14 | 18 | .036 | .032 | | Bowmanstown: raw water |
| 10 | | 0 | 0 | 0 | 7.7 | 6.4 | | 65.5 | 5.2 | 30 | 4 | | | 7 | 240 | 182 | 178 | | | | Bowmanstown: raw water, Meadow Crest Manor well |
| 11 | 2/21/66 | 0 | 0 | 0 | 7.2 | | | 58 | 22 | 135 | 5 | .000 | 1.2 | | | 210 | | | | | Palmerton: treated water |

and Sinking Spring, Pennsylvania, the mapped area has not been adversely affected by any major earthquakes of historical record.

The location of epicenters of earthquakes with Mercalli intensities of V-VI (quakes felt by nearly everyone in the epicentral area; some dishes and windows broken; some cracked plaster, etc.) in Lehigh and Northampton Counties are given by Bromery (in U.S. Geol. Survey, 1967).

## MINERAL RESOURCES

Many naturally occurring or man-made resources in the Lehighton and Palmerton quadrangles have been exploited or are potentially usable. Their use has contributed to the economic development of the area and to the location of the areas of greatest population density. Decisions concerning land use will have to take into account the location of potential resources.

### SAND

Nearly a half million tons of general-use and refractory sand are produced yearly from the Middle Devonian Palmerton Formation at several quarries between Little Gap in the eastern part of the mapped area and Andreas, 16 miles to the southwest in Schuylkill County. The production of sand at these quarries represents the only major utilization of natural economic resources in the mapped area north of Blue Mountain.

The geology of the Palmerton Formation is discussed elsewhere (see sections on stratigraphy and structure). Emphasis is placed on the clay and hematite contaminants which affect the quality of this unit. The clay is a source of alumina contaminant, but the alumina can usually be reduced to a minimum quantity by washing after crushing of the sandstone. The hematite represents a more serious contaminant which often results in waste rock because of the difficulty of removal. Excess silica cementation produces a quartzitic rock which is difficult to crush and often results in considerable waste rock. For a more extensive discussion of these aspects, the reader is referred to Sevon (1970).

The Palmerton Formation is extensively folded into a series of plunging overturned anticlines and synclines which will hereafter be called antiforms and synforms for simplicity. These structures control the suitability of quarry sites in the Palmerton Formation. Figure 173 shows cross sections and map patterns of three common structural settings in

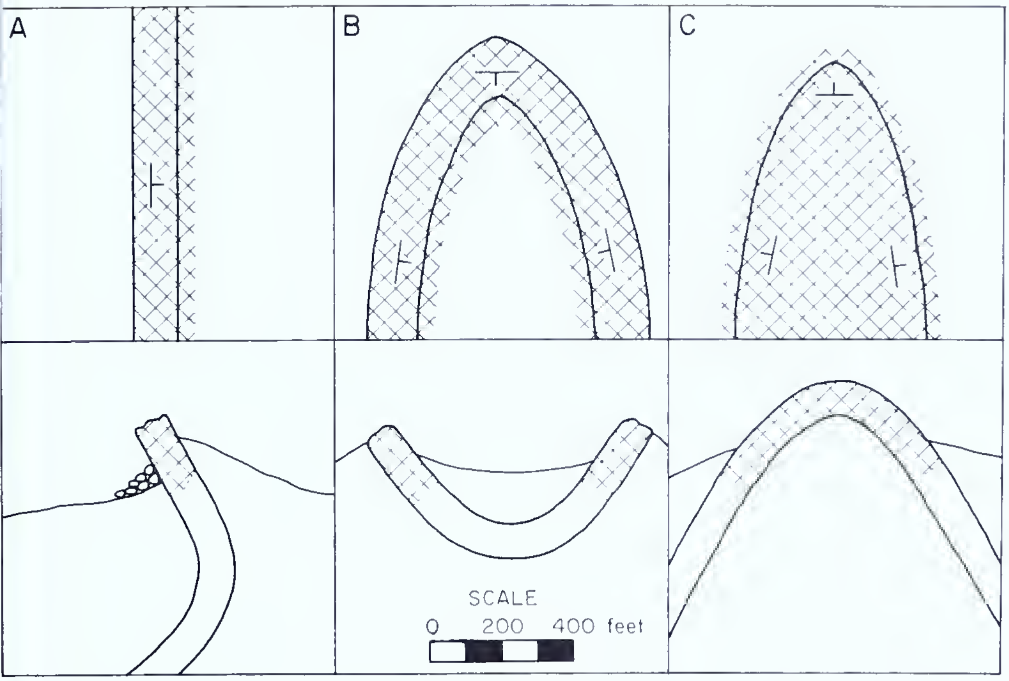

Figure 173. Map patterns (upper set) and cross sections (lower set) of three structural settings of the Palmerton Formation in the mapped area. The structural settings are rated for quarry site desirability as follows: A, poor, B, good; C, best. Cross-hatch pattern indicates area of potential sandstone removal.

the Palmerton Formation of the mapped area. The patterned areas indicate relative amounts of sandstone which might be quarried in each structural situation. Part A shows a steeply dipping linear ridge, the least desirable quarry site because the thickness of the unit, generally less than 100 feet, requires a long narrow quarry which cannot be excavated to a great depth because of the weak nature of the adjacent units.

Part B shows the plunging synform, a more desirable structural setting for a quarry site. As long as overburden is not excessive, a much larger amount of sandstone can be quarried in this situation. Particularly desirable is the nose of a plunging fold where an extensive area of sandstone is available.

Part C shows the plunging antiform, the most desirable quarry site. In such structural settings very little or no overburden exists and a large quantity of sandstone can be quarried in a relatively small area.

## Existing Quarry Operations

Existing quarry operations in the Palmerton Formation in the mapped area occur at Little Gap, Palmerton, and Germans (Plate 1). Also included in this discussion is the operation at Andreas just southwest of the mapped area. Production figures and other basic data were supplied by the quarry operators, but the conclusions about the relevancy of the local geology to the quarry operations are those of Sevon. A more extensive discussion of these operations is given elsewhere (Sevon, 1970).

North American Refractories Company at Little Gap has been producing about 100,000 tons of sand per year for refractory brick. The quarrying and processing operation includes blasting, drop balling, crushing to $\frac{5}{16}$ inch by block and secondary crusher, washing, screening, and drying. The finished sand is stockpiled and transported by railroad as needed.

The Little Gap quarry is situated at the eastern edge of the zone of Hazard paint ore occurrence and is generally lacking in hematite although some hematite does occur locally. The quarry site is ideally located on a plunging antiform having no overburden and yields a sandstone which is over 98 percent silica. Washing of the crushed rock removes most of the clay contaminant, resulting in a sand with over 99 percent silica. Cementation varies, but the sandstone reacts favorably to disaggregation, and because breakup into coherent angular fragments is preferred for refractory purposes, some silica cementation is a requisite. The company has potential future development to the west of its current operation.

The Alliance Sand Company at Palmerton has been producing between 100,000 and 300,000 tons of sand per year for blacktop, raw concrete, masonry sand, pebbles, and many other uses. The sand production involves blasting, block crushing, secondary crushing, roll crushing, washing, and screening. The sand is blended to meet specifications, stockpiled, and dispersed by truck. Structurally, the Alliance quarry site is ideally located in both plunging antiform and synform structures. Some overburden problems will occur as the operation progresses toward the Lehigh River in the synform, but the antiform is ideally suited for unimpeded quarrying. However, the Alliance quarry has some problems with accessory minerals. The quarry is in the area of greatest development of the overlying Hazard paint ore and a large amount of hematite is present in the sandstone as well as abundant silica cementation which results in a quartzitic rock. Both of these factors tend to produce considerable waste rock during the quarrying operation.

The Refractories Sand Company operates quarries at Germans and Andreas. These quarries are southwest of the main Hazard paint ore zone and do not have hematite contamination problems. The Germans quarry has been producing about 100,000 tons of sand per year, whereas the Andreas quarry has been producing between 100,000 and 150,000 tons per year. The sand from both quarries is used mainly for blacktop, raw concrete, cement block mix, and trap sand. Some of the sand from Andreas is used for refractories, but less than 10,000 tons was sold for this purpose in 1968. The operation involves blasting, drop balling, crushing, roller crushing, and screening at both sites and flotation at the Germans site. All of the sand is blended to specifications, stockpiled, and dispersed by truck.

The Refractories Sand Company has three active quarry sites and one inactive site. These sites occupy various structural settings: linear ridge, plunging synform, and plunging antiform. The quality of sandstone is excellent in all of the sites and extraction of the sandstone is hindered only by the overburden in some places. The sandstone in this area tends to be somewhat finer grained than that in the Palmerton Formation farther to the northeast and this, in combination with a general ease in sandstone breakup, tends to create a sand slightly deficient in coarse grade sizes.

## Potential Areas of Palmerton Development

In general, existing quarry operations already occupy the most favorable structural settings for exploitation of the Palmerton Formation in the mapped area. The outcrop belt of the Palmerton exposes the sandstone almost continuously across the mapped area, but the narrow linear ridge which is most common is the least desirable site for a quarry operation. Considerable potential for development occurs west of Buckwha Creek in the small plunging folds developed there, and some potential remains in two small formerly operated quarries immediately north of Palmerton (Plate 1). Any development of sand production in the zone between Little Gap and Lizard Creek to the southwest may anticipate hematite as a contaminant, whereas development to the southwest of Lizard Creek or to the northeast of Little Gap may provide sand of sufficient quality for glass production.

## Other Potential Sources of Sand

The Ridgeley Formation has virtually the same composition and same outcrop distribution as the Palmerton Formation, but is somewhat coarser and much thinner than the Palmerton Formation. The Ridgeley is also much less resistant to erosion than the Palmerton and seldom forms the crest of Stony Ridge. Consequently, it seldom occupies a favorable position for quarry operation and may not be thick enough to warrant expensive quarry development. The unit remains a potential source of high silica sand for some future time when demand and costs warrant development of the unit.

There are no other currently exploited sources of sand in the mapped area. Surficial deposits are a potential source of sand and gravel, and are discussed below.

## SAND AND GRAVEL IN SURFICIAL DEPOSITS

As described in the section on surficial geology, there are a variety of deposits that may be a source for sorted sand and gravel, although only a few might have potential value. None have been exploited to any great degree. Grain-size distribution for selected samples is shown in Figure 132, the percentages of clay, silt, sand, and gravel are given in Table 9, and statistical parameters are given in Table 11.

Alluvium along the Lehigh River and Aquashicola Creek (samples 1-3, Table 9) contains large quantities of sand. Thickness of the alluvium above water level is generally less than 10 feet, and, as shown on the geologic map (Plate 2), areas where the alluvium is exposed and where it may be conveniently extracted are generally small. Therefore, very large sand resources are not available. The problem of proximity to water level must be considered if the sand is to be removed.

Large quantities of sand and gravel are available in Wisconsinan outwash in the valley of Aquashicola Creek. The thickness of this deposit is more than 20 feet in most parts of the valley and may be more than 50 feet in many parts (see page 217). The percentages of sand, gravel, silt, and clay in two samples of Wisconsinan outwash are given in Table 9. In general, the pebbles in the outwash are fresh sandstone and limestone, but some shale and siltstone pebbles and weathered pebbles may make the gravel unsuited for some uses as an aggregate.

Outwash of Illinoian(?) age is located in many places along the major valleys. The outwash contains appreciable quantities of sand and gravel (samples 6-8) and may be more than 20 feet thick in many places. However, its use as a source for sorted materials may be limited because of its deep weathering; cobbles may have weathering rinds at least three inches thick and some pebbles are completely rotted. Moreover, some deposits may have large boulders (see Figure 117), making extraction difficult.

## PAINT ORE

The Hazard paint ore member of the Buttermilk Falls Limestone was formerly a major economic resource in the mapped area. Mining of the paint ore started in 1856 and continued until 1947 with a total output estimated at well over 200,000 tons. The geology and mining of the Hazard paint ore have been discussed by Hill (1887), Hesse (1891), Eckel (1907a & b), Burchard (1909), Agthe and Dynan (1910), Miller (1911), Kindle (1912), and Miller (1933). Willard and Whitcomb (1938) discussed fauna from this member.

The Hazard paint ore extends from Little Gap (east) to Balliet (west) and is best developed (as proved by mining) between Hazard and Little

Gap. The unit is exposed only along the Northeastern Extension of the Pennsylvania Turnpike. Fresh paint ore is hard, blocky, light metallic blue, fine grained, arenaceous and sometimes distinctly laminated. The rock oxidizes rapidly and becomes red when exposed to air. Small particles of pyrite are scattered throughout the material. The rock has a specific gravity of 3.2 to 4.0 and is an iron carbonate in the unweathered state. Table 23 presents four chemical analyses of finished paint ore and one analysis of raw paint ore.

Mining methods used in extracting the ore are outlined by Miller (1933, p. 157-158) and consisted mainly of stoping of the paint ore along bedding strike. Large quantities of water were encountered in many of the mines and free running sand in some of the mines. Water was one of the factors which contributed to the eventual abandonment of the mining operation.

Preparation of the paint ore is detailed by Miller (1911, p. 57; 1933, p. 158) and involved only two processes: calcination and grinding. In the calcination process raw ore (reduced to 6-inch-diameter fragments) was heated to a cherry-red color for about 24 hours to eliminate moisture and sulfur from the pyrite, and to convert the iron carbonate to iron oxide. Loss in the process was 20 to 25 percent. The calcinated ore was then ground so that 98-99 percent passed through a 325-mesh screen.

The finished product had some properties of a Portland cement, which contributed to its great durability. Its main market as paint for tin roofs and railroad cars has declined in recent years, but there is still a market as paint for structural steel, bridges, ships, and other industrial equip-

Table 23. *Chemical Analyses of Raw and Finished Hazard Paint Ore*

Analyses 1, 2, and 3 are of finished paint ore (Eckel, 1907b); analysis 4 is of finished paint ore (Hill, 1887); and analysis 5 is of raw paint ore (Hill, 1887).

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ | 37.20% | 37.20% | 35.30% | 37.79% | 16.21% |
| $Al_2O_3$ | 9.60 | 9.40 | 10.70 | 10.61 | 5.49 |
| $Fe_2O_3$ | 43.30 | 42.70 | 43.30 | 41.28 | |
| MnO | .35 | 1.40 | 1.83 | 1.27 | |
| CaO | .10 | 1.70 | 2.00 | 3.00 | 3.51 |
| MgO | 3.35 | 1.70 | 1.91 | 2.03 | 1.08 |
| $SO_3$ | 2.38 | 1.88 | 1.95 | 1.94 | |
| $P_2O_5$ | .17 | .14 | .15 | .14 | |
| $CO_2$ and organic | 2.40 | 2.60 | 1.50 | 2.68 | 24.35 |
| $H_2O$ | .60 | .60 | .90 | | |
| Metallic iron | 30.30 | 29.90 | 30.30 | 28.90 | 34.60 |
| S | .95 | .75 | .78 | .77 | .67 |

ment. The finished product also has limited use as a filler in oilcloth and linoleum.

There is no information as to the amount of ore depletion during active mining, but it is doubtful if the full potential of this deposit has been realized. The structure of Stony Ridge in the Bowmanstown-Hazard area (Figure 157) is such that a large quantity of iron carbonate should occur relatively near the surface. If a demand for the ore arises in the future, modern mining techniques might allow further exploitation. Extensive quarrying of the structurally overlying Palmerton Formation in this same area might result in exposure of the Hazard paint ore for easy extraction.

## SLATE

Slate in the Lehighton and Palmerton quadrangles is found in the Martinsburg Formation of Ordovician age, and to a lesser extent in the Mahantango and Marcellus Formations of Devonian age. Slate is a fine-grained rock that can be split into thin, smooth slabs and has a variety of uses.

### Slate in the Martinsburg Formation

The first slate quarry in Pennsylvania was operated in 1812 near Bangor (Merriman, 1898), and since then more than 400 quarries have been opened up in the slate belt in the Martinsburg Formation of Northampton and Lehigh Counties in eastern Pennsylvania. At present, less than a dozen of these quarries are active, but, even so, Pennsylvania still leads in the production of slate in the United States. According to the U.S. Bureau of Mines, 44,250 short tons of slate (dimension stone) having a value of $3,705,329 was produced in Northampton County, and 1,547 short tons was produced in Lehigh County in 1970.

In the Lehighton and Palmerton quadrangles there are 151 quarries. All are presently abandoned; the only active quarry in Lehigh County, the quarry of the Penn Big Bed Slate Company, is 300 feet south of the Lehighton quadrangle, about 1 mile west of Rextown. A description of that quarry is given in Figure 2. The quarries in the mapped area are shown on Plate 4 and listed in Table 24. Sanders (1883), Dale and others (1914), and Behre (1933) have described some of them earlier in their history.

A description of the Martinsburg Formation is given in the section on stratigraphy and the planar structures in the formation, such as bedding, cleavage, and joints, are described in the section on structural geology.

## Table 24. *Slate Quarries and Dumps in the Martinsburg Formation in the Lehighton and Palmerton Quadrangles*

The quarries and dumps are shown on Plate 4. The areal dimensions are taken from areal photographs. Depths were estimated at the quarry site or are taken from Behre (1933) or Sanders (1883); the depths in flooded quarries have not been field checked. The heights of the dumps are estimated from the topographic maps. Structural data were mostly recorded in the field; some are from Behre (1933).

| Number | Name of quarry | Approximate length and width (in feet) | Depth (in feet) | Height of adjoining dumps (in feet) | Remarks | Structural data | | | | References (1) Behre, 1933 (4) Epstein and Epstein, 1969 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Bedding | Cleavage | Joints | Other | |
| 1 | Penn Big Bed | 400 × 200 | 190 in 1969 | 50 | Only active slate quarry in Lehigh County. Products include blackboards, roofing, floor tiles, structural slate, flagging, aquarium bottoms, billiard table tops, etc. See Figure 2. | Strikes N75E, dips variably. Anticline (Figure 2). | N76-86E, 44–68SE | | Steep fault in south limb of fold. | (4) p. 178–180 |
| 2 | | 150 × 100 | | 20 | Flooded. | N82E, 83NW | N81E, 73SE | N79E, 39SE<br>N46W, 67NE<br>N39E, 46SE | | |
| 3 | Standard (west) | 300 × 175 | 100 | 50 | Sandstone beds as much as 8 feet thick. Abandoned in 1908. | N76E, 80SE, overturned. | N79E, 56SE | N10W, 60NE<br>N72W, 66SW<br>N30W, 88SW<br>N28E, 17SE | Slip cleavage: N82E, 56NW. One-foot-thick fault zone parallels bedding. | (1) p. 292 |
| 4 | Standard (east) | 90 × 90 | | 15 | Flooded; no rock exposed; at least 3 feet of till above water. Abandoned in 1908. | | | | | (1) p. 292 |

## Table 24. *(Continued)*

| Number | Name of quarry | Approximate length and width (in feet) | Depth (in feet) | Height of adjoining dumps (in feet) | Remarks | Structural data | | | | References (1) Behre, 1933 (2) Sanders, 1883 (3) Dale and others, 1914 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Bedding | Cleavage | Joints | Other | |
| 5 | Keim (west) | 160 × 120 | | 15 | Flooded. Abandoned in 1915. | N55E, 10SE in north wall; N71E, 74NW in south wall. | N78-80E, 56SE | N37W, 88SW.<br>N33W, vertical. | | (1) p. 295 |
| 6 | Keim (east) | 80 × 50 | | 15 | Flooded; about 15 feet of rock exposed in northeast corner. Abandoned in 1915. | N85E, 10NW in northeast corner; steepens to 60NW in middle of quarry. | N71E, 49SE | | | (1) p. 295 |
| 7 | Roth | 50 × 50 | | | Flooded; garbage filled. Active about 1900. | | | | | (1) p. 306 |
| 8 | | 75 × 75 | | 10 | Flooded; no rock exposed. | | | | | |
| 9 | Blue Valley | 600 × 350; irregular | 40+ | 70 | Flooded. About 30 feet of till above bedrock. See Figure 137. | Strikes N57-70E, dips variably. Three folds in quarry (Figure 137). | N79-82E, 61SE | N54W, 88SW<br>N28W, 78NE | | (1) p. 306 |
| 10 | Eureka (Old Eureka on west and New Eureka on east, combined). | 450 × 350; irregular | 135+ | 90 | Flooded; 8 feet of till overburden. Operating in 1927. See Figure 137. | Strikes N73-84E, dips variably. Two folds in quarry (Figure 137). | N67-72E 65-71SE | N56W, 88SW<br>N67E, 87NW | | (1) p. 307-308<br>(3) pl. 18; p. 107 |
| 11 | Mountain | 325 × 280 | 150 | 90 | Flooded. Last operated about 1918. See | Strikes N40-85E, dips variably. Two folds in | N53-78E. 53-77SE | | | (1) p. 308 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 12 | Pittston? | 180 × 75 | 30 + | 80 | Flooded. | N63E, 33SE in southeast corner. Anticline in middle of quarry (Figure 137). | N78E, 75SE | N74E, 45NW<br>N76W, 78SW | |
| 13 | Pittston (west) | 325 × 100 | 200± | 80 | Flooded. | N76E, 40SE in north wall. Two folds in quarry (Figure 137). | N73E, 40SE | | (1) p. 308 |
| 14 | Pittston (east) | 350 × 100 | 200± | 80 | Flooded. | | | | (1) p. 308 |
| 15 | East Berlin? | 200 × 130 | | 20 | Flooded. No bedrock exposed above water. About 25 feet of till above water. | | | | (1) p. 308, 310 |
| 16 | Blue Ridge (west) | 230 × 230 | 90 + | 100 | Flooded; water covers quarries 16-19. | Syncline. Beds dip 80NW on south limb and dip 26S on north limb. | | | (1) p. 311-312 |
| 17 | Blue Ridge (east) | 240 × 125 | 120 + | 100 | Flooded. Operations began in 1927. | Same as quarry 16. | N75E, 67SE | Many joints observed by Behre, 1933, p. 311. | (1) p. 311-312 |
| 18 | Pennsylvania | 160 × 160 | | 100 | Flooded. | Same as quarry 16. | N70E, 62SE | | (1) p. 312 |
| 19 | Star | 160 × 125 | | 100 | Flooded. | Same as quarry 16. | | | (1) p. 312 |
| 20 | Old Cambridge | 260 × 150 | 120 | 100 | Flooded. Idle since 1912. | Syncline. N73E, vertical in south corner; N75E, 31SE in north corner. | N68-73E, 57-73SE | N86E, 14NW<br>N29W, vertical. | (1) p. 312<br>(2) p. 116 |

## Table 24. *(Continued)*

| Number | Name of quarry | Approximate length and width (in feet) | Depth (in feet) | Height of adjoining dumps (in feet) | Remarks | Structural data: Bedding | Structural data: Cleavage | Structural data: Joints | Structural data: Other | References (1) Behre, 1933 (2) Sanders, 1883 |
|---|---|---|---|---|---|---|---|---|---|---|
| 21 | | 260 × 90 | 75? | 60 | Flooded. Three coalescing quarries. | N77E, vertical, in west corner. | N71E, 52SE | | | (1) p. 310-311 |
| 22 | Blue Diamond | 100 × 60 | | 30 | Flooded. No bedrock exposed. | | | | | (1) p. 313-314 |
| 23 | Blue Diamond | 80 × 80 | | 30 | Flooded. About 10 feet of slate exposed above water. | N68E, 80SE, overturned. | N83E, 46SE | | | (1) p. 313-314 |
| 24 | Blue Diamond | 100 × 120 | | 30 | Filled with garbage. Garbage dumps for Borough of Slatington. No bedrock exposed. | Nearly horizontal. | N80E, vertical. | | | (1) p. 313-314 |
| 25 | Cambridge shaft? | 50 × 30 | 225? | 30 | Narrow, steep. inaccessible. Tunnel at bottom. | Dips gently SE. | Steep to SE. | | | (1) p. 313 |
| 26 | Cambridge shaft | 50 × 30 | 225? | 50 | Narrow, steep, inaccessible. Tunnel at bottom. | | | | | (1) p. 313 |
| 27 | Cambridge shaft | 40 × 30 | 220 | 50 | Narrow, steep, inaccessible. Tunnel at bottom. | N75E, 20SE | N75E, 78SE | | | (1) p. 313 |
| 28 | Cambridge shaft | 30 × 30 | 195 | 50 | Narrow, steep, inaccessible. Tunnel at bottom. | | | | | (1) p. 313 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 29 | Cambridge shaft | 40 × 40 | 80+ | 50 | Narrow, steep, inaccessible. Tunnel at bottom. | Dips moderately NW. | Nearly vertical. | | | |
| 30 | | 100 × 100 | 100 | 100 | Cut into hillside. | N58E, 28SE | N69E, 77SE | | | (1) p. 311 |
| 31 | New York quarry and tunnel | 300 × 100 | 80 | 30 | Cut into hillside. Tunnel extends at least 400 feet in a westerly direction from eastern side of quarry. | Syncline. N74E, 82NW at south; N70W, 7SW at north. | N58-72E, 37-47SE | N32W, 87NE<br>N56W, 73SW<br>N88W, 85SW<br>N44E, vertical. | Quartz- and calcite-filled shear zone near bottom of quarry dips gently SE. | (1) p. 318-319<br>(2) p. 115 |
| 32 | | 120 × 70 | | 15 | Flooded, in creek. Rock exposed in hillside to south. | N72E, 61NW | N60E, 31SE | N40W, 72SW | | (1) p. 314 |
| 33 | | 80 × 30 | | 10 | Flooded. Bedrock is slumped. | | | | | |
| 34 | | 120 × 80 | | 50 | Flooded. About 40 feet of rock above water. | N67E, 45SE, overturned. | N64E, 23SE | N76E, 39NW<br>N41W, 75SE | | (1) p. 315 |
| 35 | | 100 × 60 | | 50 | Flooded; cut into hillside. | N73E, 12SE | N75E, 67SE | | | (1) p. 315 |
| 36 | | 30 × 30 | 20 | 40 | Overgrown. | N77E, 68SE, overturned. | N77E, 68SE | N22W, 76NE<br>N55E, 18NW | | (1) p. 317-318 |
| 37 | | 160 × 140 | 50 | 40 | | N81E, 40NW in north wall; N3E, 7SE in south wall. | N72-76E, 62-85SE | N5W, 84NE | Small fault at south end (see Behre, 1933, p. 315-316). | (1) p. 315-316 |
| 38 | Welshtown tunnel | 20 × 20 | 20 | | Flooded tunnel extends at least 50 feet into hill. Opened prior to 1883. | N63E, 16SE | N74E, 70SE | N8W, 88NE<br>N31E, 72NW | | (1) p. 315<br>(2) p. 115 |

Table 24. (Continued)

| Number | Name of quarry | Approximate length and width (in feet) | Depth (in feet) | Height of adjoining dumps (in feet) | Remarks | Structural data |  |  |  | References (1) Behre, 1933 (2) Sanders, 1883 (3) Dale and others, 1914 |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | Bedding | Cleavage | Joints | Other |  |
| 39 | Thomas and Roberts | 90 × 70 |  | 20 | Filled with garbage. |  |  |  |  | (1) p. 314 |
| 40 | Thomas and Roberts | 60 × 60 |  | 15 | Flooded. Operated about 1900. | N77E, 33SE | N85E, 52SE |  |  | (1) p. 314 |
| 41 | Thomas and Roberts | 40 × 30 |  | 10 | Flooded. About 15 feet of rock exposed. | N65E, 24SE | N68E, 45SE | N68W, 53NE<br>N13W, 88SW |  | (1) p. 314 |
| 42 | Old Welshtown (Stelz) | 140 × 120 | 50+ | 20 | Flooded. No outcrops above water. |  |  |  |  | (1) p. 314 |
| 43 | Stelz | 70 × 40 |  | 10 | Overgrown. | N76E, 74SE, overturned. | N82E, 64SE | N31W, 76NE<br>N15W, 10NE |  | (1) p. 314-315 |
| 44 | Fullmer | 200 × 170 | 100+ | 50 | Flooded. Syncline. See Figure 136D. Old quarry. Opened before 1880. | N48E, 47SE, overturned in south end; N74E, 18SE in north end. Syncline. See Figure 136D. | N52-77E, 40-85SE | N63E, 68NW<br>N42W, vertical. | Slip cleavage: N45E, 14NW. | (1) p. 318 |
| 45 | Keystone | 80 × 40 | 40? | 70 | Partly filled with garbage. Formerly connected with quarry no. 46. | N80W, 31NE | N50E, 17SE |  |  | (1) p. 318<br>(2) p. 115 |
| 46 | Keystone | 70 × 70 |  | 90 | Partly filled with garbage. | N66E, 30SE | N80E, 65SE |  |  | (1) p. 318 |
| 47 |  | 200 × 80 | 10+ | 75 | Tunnel in hillside more than | N84E, 31SE | N87E, 76SE | N6W, 73NE<br>N70E, 71NW |  | (1) p. 319 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 48 | | 70 × 40 | | 15 | Flooded. | | | | | (1) p. 319 |
| 49 | | 30 × 30 | | 10 | Prospect. | N82E, 67SE, overturned. | N83E, 53SE | | | |
| 50 | | 20 × 20 | | 5 | Prospect. | N82E, 48SE | N68E, 54SE | | | |
| 51 | Bill Hughes | 100 × 60 | 50 + | | Flooded. | N66W, 15SW on south; N64E, 57NW on north. | N79-82E, 65-73SE | N27W, 75NE | | (1) p. 319<br>(3) p. 107 |
| 52 | Lucerne | | | 15 | Completely filled in. Worked in 1902-1905. | | | | | (1) p. 320 |
| 53 | Lehigh Gap | 130 × 120 | 60 + | 40 | Flooded. Abandoned in 1924. | N88E, 34SE | N84E, 58SE | | Anticlinal crest in north wall. | (1) p. 319-320 |
| 54 | | 100 × 50 | | | Prospect. | N86E, 55SE, overturned. | N81E, 50SE | N52W, 81NE<br>N59E, 73NW | | |
| 55 | Riverside | | | 15 | Flooded. No rock exposed above alluvium. | | | | | (1) p. 321 |
| 56 | | 10 × 10 | 8 | | Prospect. | N63E, 44NW | N63E, 46SE | N32W, 66NE | | |
| 57 | | 10 × 10 | 8 | | Prospect. | N87E, 36SE | N81E, 48SE | N52E, 71NW<br>N19W, 66NE | | (1) p. 321 |
| 58 | Caskey and Emack | 80 × 80 | 75? | | Flooded. No rock exposed. | | | | | (1) p. 321 |
| 59 | | 160 × 130 | About 300 (see remarks). | | Filled in by American Nickeloid Co., Walnutport, Pa., in 1969. | N58E, 23SE | N76E, 57SE | | | (1) p. 321 |
| 60 | | 30 × 25 | 20 | | | N72E, 50SE, overturned. | N72E, 40SE | | | (1) p. 324-325 |
| 61 | | | | | Small, overgrown. | N67E, 52SE, overturned. | N77E, 35SE | | Slip cleavage: N53E, 56NW. | |

## Table 24. *(Continued)*

| Number | Name of quarry | Approximate length and width (in feet) | Depth (in feet) | Height of adjoining dumps (in feet) | Remarks | Structural data |  |  |  | References (1) Behre, 1933 (2) Sanders, 1883 (3) Dale and others, 1914 |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | Bedding | Cleavage | Joints | Other |  |
| 62 | West Brensinger | 60 × 60 | 20+ | 40 | Flooded. No slate exposed below till. |  |  |  |  | (1) p. 321 |
| 63 | West Brensinger | 100 × 90 | 20+ | 40 | Flooded. No slate exposed below till. |  |  |  |  | (1) p. 321 |
| 64 |  | 25 × 25 | 30 | 15 |  | N79E, 52SE, overturned. | N83E, 46SE | N38W, 82SW | Slip cleavage: N62E, 56NW. | (1) p. 321-322 |
| 65 |  | 50 × 30 |  |  |  | N69E, 62SE, overturned. | N82E, 47SE | N32W, vertical. |  |  |
| 66 |  | 60 × 40 |  |  | Flooded. | N65E, 82SE, overturned. | N83E, 50SE | N8W, 62NE<br>N12E, 8SE |  |  |
| 67 | David Williams | 400 × 200; irregular | 90+ | 70 | Flooded. |  |  |  |  | (1) p. 322<br>(2) p. 112 |
| 68 | Peters (Owen Williams) | 200 × 150 | 80+ | 50 | Flooded. | N85E, 18SE in NE corner; N88E, 30NW in SE corner. Syncline runs through quarry. | N74E, 61SE | N13W, vertical. | Slip cleavage: N62E, 20NW. | (1) p. 322<br>(2) p. 112 |
| 69 | Rudolf | 120 × 120, irregular |  | 30 | Flooded, partly filled with waste slate. | N83E, 88NW in NW corner. | N83E, 58SE | N5E, 71SE<br>N26W, 85NE |  | (1) p. 322-323 |
| 70 | Rudolf | 130 × 150; irregular |  | 20 | Flooded. Opened about 1880. Abandoned 1893. | N78E, 35SE in north wall; N82E, vertical in SE corner. Syncline; see Figure 136C, | N80-86E, 52-64SE | N44W, 70NE<br>N82E, 66NW |  | (1) p. 322-323 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | circular | | | depth. | north wall; N85E, 68NW in south wall. | | N20W, vertical. | | (2) p. 111-112, 119<br>(3) p. 100-101 |
| 72 | | 30 × 20 | | 50 | | N68E, vertical. | N78E, 58SE | N17W, 72NE | Slip cleavage: N88E, 28NW. | |
| 73 | | 100 × 100 | | 40 | Partly filled with waste slate. Once continuous with quarry no. 74. | N82E, vertical | N88E, 47SE | N71E, 44SE<br>N8W, 87NE | | (1) p. 324 |
| 74 | | 70 × 50 | 60 + | 20 | | N78E, 87NW | | | | (1) p. 324 |
| 75 | | 70 × 50 | 40 + | | Flooded. | N75E, 68NW | N70E, 64SE | | | |
| 76 | | 100 × 70 | 40 | 50 | Partly filled with waste slate. | N72E, 26NW | N88W, 61SW | N18W, 87NE | | (1) p. 324 |
| 77 | | 60 × 30 | 60 | 10 | | N77E, 27SE | N86E, 51SE | N73W, 80NE<br>N79E, 61NW<br>N5W, 86NE | | (1) p. 324 |
| 78 | | Small | | | | N80E, 33SE | N82E, 42SE | N68E, 76NW<br>N18W, 66NE | | |
| 79 | | Small | 10 | | | N67E, 34NW | N75E, 48SE | N53W, vertical | | |
| 80 | Larrabee | 140 × 100 | 60 + | 20 | Flooded. Opened in 1915. | N61E, 75SE, overturned. | N71E, 38SE | N17W, 79NE | Slip cleavage. | (1) p. 325 |
| 81 | Larrabee | 60 × 50 | 60 | 15 | Flooded; overgrown. Opened in 1915. | N60E, 65SE, overturned. | | | | (1) p. 325 |
| 82 | | 20 × 20 | 20 | | | N86W, 32SW | N74E, 53SE | N56E, 80NW<br>N15W, 76NE | | |
| 83 | Benninger? Oak Hill? | 150 × 70 | 60 + | 40 | Flooded. Abandoned in 1912. | N54E, 74SE, overturned. | N72E, 50SE | N43E, 60NW<br>N24W, 82SW | | (1) p. 325-326 |
| 84 | Loretto? | 100 × 90 | | | Flooded. | N62E, 85SE, overturned. | N76E, 47SE | N24W, 87NE | | (1) p. 325-326 |
| 85 | | 30 × 10 | 40 | 10 | | N35E, 57NW | N72E, 47SE | N35W, 73NE | Slip cleavage: N35E, 57NW. | |

## Table 24. *(Continued)*

| Number | Name of quarry | Approximate length and width (in feet) | Depth (in feet) | Height of adjoining dumps (in feet) | Remarks | Structural data |  |  |  | References (1) Behre, 1933 (2) Sanders, 1883 |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | Bedding | Cleavage | Joints | Other |  |
| 86 |  | 70 × 20 | 30 |  |  | N63E, 51SE | N53E, 75SE | N59W, 75NE |  | (1) p. 326 |
| 87 |  | 50 × 20 | 10 |  | Prospect. | N70E, 24SE | N72E, 56SE | N14W, 84NE |  |  |
| 88 | Peters | 80 × 70 | 80 | 30 | Overgrown; partly filled with waste slate. | N72E, 3NW in south wall; overturned in north wall. | N75E, 45SE in south wall. |  |  | (1) p. 326-327 |
| 89 | Peters | 80 × 70 | 100 | 30 | Flooded. | N75E, 63SE, overturned. | N73E, 46SE |  |  | (1) p. 326-327 |
| 90 | Griffith | 120 × 100 | 70 | 30 | Garbage dump for town of Walnutport. | N68E, 67SE, overturned. | N65E, 40SE |  |  | (1) p. 327–328 |
| 91 | Hughes | 80 × 60 | 80+ | 30 | Flooded. Garbage dump for town of Walnutport. |  |  |  |  | (1) p. 327-328 |
| 92 | Hughes | 70 × 60 | 70 | 30 | Garbage dump for town of Walnutport. | N73E, 65SE, overturned. | N68E, 44SE |  |  | (1) p. 327-328 |
| 93 | Hughes and Griffith (Lamb and Ditchett) | 160 × 60 | 35+ | 30 | Garbage dump for town of Walnutport. | N61E, 58-75SE, overturned. |  |  | One-foot-wide shatter zone at south end. | (1) p. 327-328 |
| 94 | Peters-Atlas | 200 × 150 | 100+ | 80 | Flooded. Opened 1905. | N72E, 70SE, overturned. |  |  |  | (1) p. 328 |
| 95 | Peters-Atlas | 220 × 180 | 45+ | 80 | Flooded. Opened 1905. | N72E, 73SE, overturned. | N72E, 39SE |  |  | (1) p. 328 |
| 96 | Peters-Atlas | 150 × 110 |  | 50 | Flooded. Opened 1905. |  |  |  |  | (1) p. 328 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 97 | Atlas | [illegible] | [illegible] | [illegible] | Flooded. | [illegible] overturned. | [illegible] | | [illegible] N82E, 48SE. | [illegible] |
| 98 | Atlas | 80 × 50 | | 50 | Flooded. | | | | | (1) p. 330 |
| 99 | Atlas | 50 × 50 | 40+ | 50 | Flooded. | N70E, 85SE, overturned. | N75E, 57SE | | | (1) p. 330 |
| 100 | Provident (Kester's Meadow?) | 360 × 300 | 140? | 70 | Flooded. | N75E, 15SE in northwest corner; dips steeply to NW in south wall. | N70E, 60SE | | | (1) p. 328-329<br>(2) p. 111 |
| 101 | | 100 × 30 | 40 | | Cut into side of hill. | N69E, 54SE, overturned. | N75E, 48SE | | Slip cleavage: N63E, 38NW. | |
| 102 | Genuine Washington | 500 × 250 | 190+ | 90 | Flooded. Two quarries separated by submerged rib. Covered by 40 feet of overburden. Three tunnels at bottom. | N65-72E, 70SE, overturned to vertical; flattens with depth. | N72E, 40SE | N75E, 30NW | Slip cleavage locally developed. | (1) p. 329-330 |
| 103 | Roberts | 150 × 130 | 240? | 30 | Flooded. No rock exposed above water. Opened 1920; abandoned 1925. | | | | | (1) p. 330-331 |
| 104 | Hahn and Griffith | 130 × 60 | | 10 | Flooded. No rock exposed. | | | | | (1) p. 331 |
| 105 | John Benninger | 100 × 70 | 40+ | 30 | Flooded. Used for garbage dump. | N53E, 88NW | N68E, 62SE | N36W, 71NE | | (1) p. 331 |
| 106 | | 15 × 30 | 25 | 10 | Overgrown. | N68E, 37SE | N84E, 67SE | N61E, 71SE<br>N20W, 85NE | | (1) p. 331 |
| 107 | | 80 × 50 | | 10 | Flooded. | N67E, 20NW | N74E, 78SE | N2W, 64NE | | |
| 108 | Seybold? | 110 × 70 | | 10 | Flooded. | N87E, 62NW | N82E, 74SE | | | (1) p. 331 |

Table 24. *(Continued)*

| Number | Name of quarry | Approximate length and width (in feet) | Depth (in feet) | Height of adjoining dumps (in feet) | Remarks | Structural data |  |  |  | References (1) Behre, 1933 (2) Sanders, 1883 |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | Bedding | Cleavage | Joints | Other |  |
| 109 |  | 120 × 100 |  | 20 | Flooded. Fish. | N66E, 70SE, overturned. | N63E, 58SE |  |  |  |
| 110 | New York and Pennsylvania | 160 × 100 |  | 20 | Flooded. | N86W, 63SW, overturned. | N81W, 47SW | N87W, 72NE |  | (2) p. 110-111 |
| 111 |  | 60 × 60 |  |  | Flooded. No rock exposed. |  |  |  |  |  |
| 112 | Prudential | 80 × 70 |  | 30 | Flooded. | N72E, 80SE, overturned. | N84E, 33SE | N27W, 73NE |  | (1) p. 331 |
| 113 | Prudential | 400 × 230 | 150 | 70 | Flooded. No rock exposed. Abandoned about 1920. |  |  |  |  | (1) p. 331-332 |
| 114 | Newville | 50 × 40 | 40+ | 80 |  | N76E, 47SE | N71E, 67SE | N34W, 87NE<br>N68E, 83 NW | Slip cleavage: N58E, 27 NW. | (2) p. 110 |
| 115 | Banner | 400 × 250 |  | 70 | Flooded. Opened about 1880. | N70E, 66SE, overturned. | N70E, 59SE | N77E, 60NW<br>N22W, 66SW<br>N28W, 41NE |  | (1) p. 332 |
| 116 | Oplinger | 130 × 70 |  | 15 | Flooded. | N72E, 68SE, overturned. | N80E, 38SE |  |  | (1) p. 332 |
| 117 | Madoc | 200 × 150 |  | 30 | Flooded. No rock exposed. Opened about 1897. |  | N65E, 40SE |  |  | (1) p. 332 |
| 118 | Pearl (York-Lien) | 120 × 100; irregular |  | 30 |  | N68W, 23SW | N67E, 36SE |  |  | (1) p. 332-333 |
| 119 | West Montgomery | 350 × 330 | 120 | 30 | Flooded. Opened 1895. | East, 33S | N58E, 65SE | N9E, 58SE<br>N68E, 75NW |  | (1) p. 333 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | gomery | | | | for garbage dump. No rock exposed. Opened 1895. | | | | |
| 121 | Haynes | 130 × 80 | | 50 | Flooded. No rock exposed. | | | | (1) p. 333-334 |
| 122 | Haynes | 120 × 70 | | 50 | Flooded. No rock exposed. | | | | (1) p. 333-334 |
| 123 | | 70 × 50 | | 10 | Flooded. | N85E. 75NW | N82E, 51SE | | |
| 124 | East Haynes | 80 × 70 | 50+ | 60 | Flooded. Abandoned 1917. | N78E, 85SE, overturned. | N70E, 48SE | | (1) p. 334 |
| 125 | Williams | 100 × 80 | | 15 | Flooded. Opened 1865. | N84E, 21SE | N75E, 30SE | | (1) p. 334 |
| 126 | Continental | 190 × 90 | | 30 | Flooded. | N62E, 82NW | N75E, 46SE | N38W, 70NE | (1) p. 334<br>(2) p. 110 |
| 127 | Armiento | 150 × 70 | | | Flooded. No rock exposed. | | | | (1) p. 334 |
| 128 | Wales-Bangor (Federal Slate Company) | 150 × 100 | | 20 | Flooded. | N77E, 63SE, overturned. | N85W, 46SW | | (1) p. 334-335 |
| 129 | | 50 × 50 | | 20 | Completely filled in. | | | | (1) p. 335 |
| 130 | Sewell | 130 × 100 | 50+ | 30 | Flooded. | N60E, 58SE, overturned. | N69E, 30SE | | (1) p. 335 |
| 131 | Sewell | 100 × 100 | 40+ | 30 | Flooded. | N52E, 51SE, overturned. | N72E, 45SE | N26W, 71SW | (1) p. 335 |
| 132 | | Small | 15 | | Prospect. | N52E, 62SE, overturned. | N77E, 30SE | N48W, 87SW | |
| 133 | | 80 × 50 | | 15 | | N52E, 64SE, overturned. | N76E, 37SE | | (1) p. 335 |
| 134 | | 80 × 50 | | 50 | | N56E, 76SE, overturned. | N70E, 34SE | | (1) p. 335 |

Table 24. *(Continued)*

| Number | Name of quarry | Approximate length and width (in feet) | Depth (in feet) | Height of adjoining dumps (in feet) | Remarks | Structural data | | | | References (1) Behre, 1933 (2) Sanders, 1883 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Bedding | Cleavage | Joints | Other | |
| 135 | | 100 × 70 | 50 | 50 | | N55E, 59SE, overturned. | N68E, 50SE | N78E, 65NW<br>N60W, 82SW | | (1) p. 335 |
| 136 | | 140 × 70 | | 40 | Flooded. Opened 1870. See Figure 136B. | N68E, 60SE, overturned. | N72E, 50SE | N15W, 26NE | | (1) p. 336 |
| 137 | | 170 × 150 | | 30 | Flooded. See Figure 136D. | N80E, 32SE | N74E, 48SE | N8W, 83NE<br>N28W, 62NE | | (1) p. 336 |
| 138 | | 200 × 120 | | 40 | | N69E, 48NW | N74E, 51SE | | | (1) p. 336 |
| 139 | | 70 × 60 | | 40 | Flooded. | N30W, 15SW | N60E, 47SE | | | (1) p. 336 |
| 140 | | 80 × 60 | | 70 | Flooded. No rock exposed. | | | | | (1) p. 336 |
| 141 | Hower (Eagle) | 600 × 550: irregular | 300 | 80 | Flooded. Opened prior to 1880. | N85W, 36SW in north wall; N66E, 67SE, overturned, in west wall. | N81-85E, 37-55SE | N55E, 65SE<br>N31W, 40NE | Slip cleavage in waste blocks on dump. | (1) p. 336-337<br>(2) p. 109 |
| 142 | Gem (J. Henry) | 110 × 70 | | 15 | Flooded. Opened 1857. See Figure 136A. | N68E, 85SE, overturned in north wall. | N77E, 43SE | N30E, 68SE<br>N2W, 35NE | | (1) p. 337<br>(2) p. 109 |
| 143 | Gem | 260 × 80 | | 30 | Flooded. Opened 1857. See Figure 136A. | N78E, 35SE | N73E, 68SE | N59W, 87SW | | (1) p. 337 |
| 144 | Cambria (Harper, Henry) | 350 × 350 | 250 | 70 | Flooded. Opened prior to 1861. | N63E, 86NW | N85E, 50SE | | | (1) p. 337<br>(2) p. 108-109 |
| 145 | | 80 × 80 | | 15 | Flooded. No rock exposed. | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 146 | National | 530 × 370, irregular | 70 | Flooded. Opened in 1865. | N58E, 70SE, in southwest corner; steepens to near vertical in northeast wall. Syncline at depth. | N68E, 42SE | N4E, 60NW<br>N77W, 48NE | (1) p. 337-338<br>(2) p. 109 |
| 147 | Rept | 70 × 40 | 10 | Completely filled in. | | | | (1) p. 338 |
| 148 | | 120 × 110 | 10 | Flooded. | N75E, 58SE, overturned. | | | (1) p. 338 |
| 149 | | 100 × 100 | 20 | Flooded. | N80W, 21NE | N76E, 70SE | N13W, vertical.<br>N73E, vertical. | (1) p. 338 |
| 150 | Labar | 240 × 180 | 40 | Flooded. Opened prior to 1900. Closed about 1910. | N80E, 63SE, overturned. | N82E, 60SE | | (1) p. 253 |
| 151 | | Small | 10 | | N87W, 28SW, overturned. | N81E, 23SE | | |

### *Economics of Slate Related to Geologic Setting*

Planar structures in the slate are very important in quarry operations and may determine whether a quarry is profitable. Certain beds, or *runs,* contain high-quality slate and are followed down-dip as the slate is removed. If the angle of dip is low, the quarry will expand over a large area during slate removal; if the dip is steep, the quarry will be narrow and deep. In some quarries, the beds are so tightly folded that individual runs may be repeated several times at depth (see Figure 137).

Cleavage is very important because it is this feature that makes a rock a slate. The cleavage must be continuous through a rock, and it must not be curved or irregular (*curled*). If the angle between cleavage and a desirable bed of a given thickness is high, the length of the piece of slate is short. If that angle is low, the length of the piece of slate is, conversely, long (see Epstein, 1974). The dip of cleavage is also important because it generally forms the floor of the quarry and may be inconveniently steep. In the Lehighton and Palmerton quadrangles the cleavage is moderate to steep, averaging about 50° (Figure 154). The angles of dip of cleavage and bedding are shown on Plate 1 and given in Table 24.

Joints are natural breaks in the rock and may facilitate quarrying if they cause the slate to break into blocks that may be conveniently handled. On the other hand, if the joints are too close together or are at low angles to each other, large blocks of slate cannot be obtained and the rock is worthless. Joints, as well as faults and sometimes bedding and cleavage, are also natural channelways for the movement of ground water; consequently, in some quarries excess seepage may be a problem. Structural data on the joints that were measured at each quarry are listed in Table 24.

### *Waste from Slate Quarries*

Waste amounts to 50-85 percent of the rock taken from a quarry. It accumulates as enormous unsightly piles or dumps. The dumps, which have had little commercial use, cover land that is potentially usable for development and agriculture. Slate dump areas are shown on Plate 4, and their heights are given in Table 24. These may be used to calculate the approximate volume of material in the dumps.

### *Uses for Slate*

Slate taken from the quarries has had a variety of uses, including roofing, blackboards, aquarium bottoms, billiard table tops, electrical panels, switchboards, flagging, floor tiles, mantles, sills and treads, grave vaults, tubs, vats, sinks, laboratory table tops, well covers, and bread boards. When crushed to flour, slate is used for filler in paint, linoleum, and many other products, and when crushed for granules, in the manufacture of composition roofing.

Potential uses for waste slate in the slate dumps are given by Dale and others (1914, p. 192-193) and Behre (1933, p. 105-106). An investigation of the properties of slate in order to determine new uses for the large amounts of waste was undertaken in 1932 by the Mineral Industries Experiment Station of the Pennsylvania State College (Pennsylvania State College, 1947; Stickler and others, 1951). The uses, which would make the waste slate a valuable resource and eliminate the environmentally annoying piles, include lightweight aggregate (see O'Neill and others, 1955, p. 12-15, Table 9), mineral wool for insulation, slate-lime brick, resin-bonded molded products, roofing granules, acoustical tile, road asphalt, abrasive soap, fence posts, and filler in a large variety of products including synthetic slate, roofing mastic, plastic which requires acid resistance, oilcloth, linoleum, rubber, paints, and ceramic ware.

The abandoned quarries are large holes which have been put to various uses in eastern Pennsylvania, including a reservoir for public water supply, sites for garbage dumps (nos. 7, 24, 39, 45, 46, 90, 91, 92, 93, 105, and 120, Plate 4), and sites for oil storage. Flooded quarries are fed by ground water and many support a large fish population. There is a possible pollution hazard from the garbage dumps (see Schneider, 1970). The quarry water is connected to the ground-water system and potential pollution of nearby water wells should be investigated. If there is little possibility for pollution near a quarry and if it lies above the water table, it may be a good site for a sanitary landfill. If there is a pollution potential, it is possible that the quarries could be grouted to close off the connection to the ground-water system.

### *Hazards in Slate Quarries*

In addition to the pollution possibilities mentioned above, many flooded quarries are a safety hazard—drownings of swimmers and scuba divers have been reported.

Many faults in the quarries are filled with calcite and quartz "spar" and are zones of movement of ground water. The rock along the faults may, therefore, be rotted. This creates a serious problem in quarry operation. In many cases, removal of slate will stop at a fault. The fault is also dangerous, especially if it contains abundant water, because it is a plane above which the rock may slide into the quarry, sometimes without warning, and injure or kill workers below. Death and injury of workers due to falling rock in actively worked quarries in the slate belt of eastern Pennsylvania are all too common. Between 1960 and 1970, an average of 514 men worked in the slate quarries of eastern Pennsylvania each year.

Between 10 and 14 quarries were active each year. There were seven fatalities during this period and 368 nonfatal injuries (U.S. Bureau of Mines, unpub. data).

### *Prospecting for Slate*

The best areas for prospecting for slate follow the belt of proven slate resources shown in Plate 4. The depth of overburden (i.e., glacial deposits, colluvium, and weathered rock) should not be great. The prospective site should not have abundant deleterious sandstone mixed in with the slate; for this reason, the Ramseyburg Member of the Martinsburg Formation is not a good unit for prospecting. Using these criteria, the most likely areas for looking for slate resources are outlined in Plate 4. Procedures for prospecting, as well as descriptions of quarry and mill practice, are given by Sanders (1883, p. 138-143), Dale and others (1914, p. 167-171), Behre (1933, p. 11-21, 68-73, 81-102), Stickler and others (1951, p. 11-32), and Bowles (1955, p. 8-10). Exploration of a site should preferably begin by core drilling to determine the quality and thickness of slate and depth of overburden (glacial deposits, if present, and weathered slate or "top"). The overburden should be thin, generally less than 20 feet, in order to avoid costly stripping operations and extensive cribbing. Structural features have to be determined, such as the character of the jointing and presence of faults or curved cleavage. The locations for future waste piles have to be determined to avoid placing them over rock that remains to be worked. Drainage has to be considered; excessive water results in costly pumping, but moderate amounts of water are needed to keep the slate from becoming brittle. Finally, the slate has to be tested for such things as sonorousness, cleavability, cross fracture ("sculp" or "grain"), color and discoloration, presence of undesirable minerals, character of cleavage surface, electrical resistance, strength, toughness, elasticity, density, porosity, hardness or abrasion, corrodibility, microscopic analysis, and chemical analysis (Merriman, 1898, p. 85-89; Dale and others, 1914, p. 171-189; Behre, 1933, p. 73-81).

## Slate in the Mahantango and Marcellus Formations

Prior to 1915 some slate was produced from the Mahantango and Marcellus Formations in the mapped area. Four quarries were opened into the shale at Aquashicola and are reported by Behre (1933, p. 119-126) and Dale and others (1914, p. 108-109). The quarried product is described as a mica slate of the fading series (containing sufficient $FeCO_3$ to discolor considerably on prolonged weathering). No information is available on the amount or the quality of the slate produced from these quarries. The waste material piled near the quarries disintegrates readily, suggesting that this rock weathers fairly rapidly and is not a high-quality slate.

The only statistics available on the quarrying operations of this slate (U.S. Geological Survey, 1911, p. 565-567) indicate that roofing slate was quarried between 1909 and 1912. The reported figures for 1909 and 1910 were combined with output of quarries in York County (3 in 1909 and 4 in 1910) and indicate a total of 12,843 roofing squares (a square contains a sufficient number of pieces of any size to cover 100 square feet with allowance for a 3-inch overlap) in 1909 and 14,291 roofing squares in 1910. The price of the Carbon County roofing square was half that of the York County product, suggesting that the Carbon County product was somewhat poorer in quality.

Two abandoned slate quarries are located in the Marcellus Formation and rock in their waste piles indicates slate of poor quality. These quarries are located:

1. About 3,300 feet northwest of Harrity and 200 feet north of a minor road (state highway legislative route number 13011) on the west side of an unnamed stream which enters Pohopoco Creek 2,000 feet southwest of Harrity.
2. About 3,400 feet north of Pohopoco Creek on the west side of Sawmill Run.

One other abandoned slate quarry, in the Mahantango Formation, is located about 700 feet north of Pa. Route 895 on the west side of an unnamed stream which enters Lizard Creek about 800 feet southeast of the center of Ashfield.

## BUILDING STONE

Quartzite in the Shawangunk Formation weathers to shades of gray, pink, red, and tan and makes a durable and attractive building stone. Even-bedded slabs of the quartzite from a few inches to a foot thick may be obtained along the entire south slope of Blue Mountain. The blocks range from less than a foot to several feet long. Bedding forms the natural parting planes of these slabs and joints further break them into rectangular blocks. The most abundant blocks may be derived from float, although some loose bedrock may be scraped up with power equipment. One small operation, using a bulldozer, truck, and 4-foot hydraulic rock splitter, was in operation in 1969 in the southwest corner of the Lehighton quadrangle, 1.2 miles southeast of Germans.

Boulders of hard quartzite and sandstone in the glacial deposits have been extensively used locally as fieldstone in the construction of houses and other buildings. They may be abundant enough to be a free source of stone at the construction site.

At the present time there are no building stones being produced north of Blue Mountain. Stone (1932, p. 88-90) reports briefly on the use of some locally derived stone, but his report contains very little information.

In general, the mapped area contains large quantities of rock suitable for good-quality small dimension building stone, but little rock suitable for large dimension building stone. None of the rocks have the uniform thick bedding usually desirable for dimension stone. Almost all of the sandstones in the area are highly variable when traced along strike; therefore, they are inconsistent in dimensional character. However, small local deposits have been utilized extensively in the past.

The Palmerton Formation is the most massive sandstone of the area and dimension stone was apparently produced formerly from a small quarry on Stony Ridge immediately southeast of Bowmanstown (3,000 feet east of 75° 40′ W; 3,000 feet north of 40°47′30″ N). The rock at this quarry is quartzitic in character because it has extensive silica cementation, is massive with no apparent bedding, broken by several widely spaced joint sets, and is gray. The high quality of rock present in this quarry is atypical of the Palmerton as a whole, but typical for this area of Stony Ridge which is unusually high in silica cementation. The amount and use of the rock quarried here is not known, but the potential of the quarry has not been exhausted. The Palmerton sandstone was also quarried immediately west of the Lehigh River at Lizard Creek Junction and used for foundation construction.

Locally derived dimension stone was used exclusively in the construction of the Lehigh Canal between 1818 and 1840. Siltstones, sandstones and conglomerates of the Trimmers Rock, Catskill and Pocono Formations were quarried in small quarries near the location of use or derived from waste rock produced during excavation for a canal channel (e.g., immediately north of Long Run). The durability of these various rocks is shown by the soundness of some of the remaining Lehigh Canal locks. The rocks used in these structures generally show little or no effect of weathering after more than 125 years and do not show any marked tendency towards disintegration. Some rocks, particularly Pocono conglomerates (seen mainly to the north in the Christmans quadrangle), have cracked in response to unequal bearing pressures. The pressures resulted from load transfer as the original interstitial hydraulic cement weathered from between stone blocks.

In general, the remaining Lehigh Canal locks attest to the high quality of many of the rocks in the mapped area as potential building stones. Numerous buildings in the town of Jim Thorpe have been constructed of local stone and also attest to the quality of these rocks.

The following units might be used for production of good-quality small dimension building stone:

1. Thick coarse-grained siltstone beds of the upper half of the Trimmers Rock Formation.
2. Thick fine-grained sandstones of the Towamensing Member (Catskill Formation) and the Mauch Chunk Formation.
3. Sandstones and conglomerates of the Packerton, Berry Run, Clark's Ferry, and Duncannon Members (Catskill Formation) and the Pocono Formation.

Of particular interest might be some of the red units of the Duncannon Member (Catskill Formation) and some of the gray and white conglomerates of the Pocono Formation.

Utilization of any of these rocks for building stone should be preceded by (1) market establishment, (2) evaluation of potential stone quantity, (3) stone quality assessment, and (4) suitability of quarry site.

## FLAGSTONE

There are no known existing or former flagstone quarries in the mapped area. However, rock suitable for flagstone occurs in the upper part of the Catskill Formation.

The well-developed planar-bedded sandstones of the Clark's Ferry Member are the best potential sources of flagstone observed in the area. The character of this unit is well exposed along U.S. Route 209 immediately south of Jim Thorpe. The sandstones of the unit have uniform grain-size distribution, planar beds, good parting characteristics, and appear to be constant through moderate thicknesses and outcrop distances.

The Berry Run, Sawmill Run, and Packerton Members (Catskill Formation) are also potential flagstone sources and are listed in order of probable desirability. Some flagstones have been hand picked from sandstones of the lower Sawmill Run Member (Catskill Formation) and used to build a dry wall along the margins of the Big Chief Drive-In parking lot (west side of U.S. Route 209 north of Packerton). In general, the development of planar bedding, ease of parting, uniformity of grain size, and lateral constancy of beds decreases from the top of the Berry Run Member to the base of the Packerton Member.

The above described units offer the greatest potential for flagstone development in the mapped area, although good flagstone rock may occur locally in almost any sandstone in the mapped area. Potential users of this material should be aware that lateral continuity of any deposit may be minimal and any development of flagstone for other than small local use should be preceded by extensive investigation to prove the quality and quantity of the deposit (Glaeser, 1969).

The use of slate from the Martinsburg Formation for flagstone has already been mentioned.

## CRUSHED ROCK

Crushed rock is used as railway ballast, road base course, rip rap, drainage fill material, and coarse aggregate for concrete. Crushed rock has an angular particle shape and its limiting size and size grading can be readily controlled. Although specific requirements for any crushed rock depend upon its use, the general requirements for a satisfactory aggregate have a basic application to all crushed rock. These requirements are:

1. Must be clean.
2. Must be correctly graded in size.
3. Must be uniform in grading and quality.
4. Must be durable.
5. Must not possess any mineralogic or chemical characteristics which will react with Portland cement after mixing and placing.

Requirements 1, 2, and 3 are met readily by proper processing techniques. Requirements 4 and 5 depend upon evaluation of the lithologic and mineralogic characteristics of the source rock and failure to properly assess these characteristics may result in an undesirable aggregate.

There is no crushed rock currently being produced in the mapped area, although two crushed-rock quarries have been operating just beyond the boundaries of the area: Fanzio Brothers, Nesquehoning (about 3 miles west of Jim Thorpe), crushes Mauch Chunk Formation sandstones and siltstones for concrete aggregate, road metal, and screenings, and Huss Contracting Company, Andreas (about 2 miles southwest of the southwestern corner of the mapped area), crushes Silurian limestones for concrete aggregate, road metal, and screenings.

Rocks of the Mauch Chunk Formation occur mainly underneath the town of Jim Thorpe and are therefore not in a suitable location for quarry development in the mapped area. However, Mauch Chunk rocks nearby in the Christmans and Weatherly quadrangles are suitably situated for quarry development and that interval of the formation indicated by units 79-125 in measured section 19 is probably the most suitable for development.

The Bossardville Limestone of Silurian age was once quarried, mainly for production of lime, immediately south and downslope from the processing plant of the Alliance Sand Company, Palmerton. This limestone occurs on the south side of Stony Ridge across the entire mapped area and is a potential source of crushed rock. However, in most places the limestone beds have steep dips and could only be quarried in a deep and narrow pit. Overburden and deep weathering also limit the potential development of these rocks in most places.

Other potential sources, listed in descending order of estimated quality, are the Packerton, Towamensing, Sawmill Run, Berry Run, and Clark's Ferry Members (Catskill Formation) and the Spechty Kopf Formation.

The somewhat massive and thick-bedded sandstones of the Packerton Member have good potential for crushed rock and some of this rock has been quarried about one-fourth mile north of the mapped area northeast of Walcksville for use in construction of the Beltzville Dam. The sandstone is not known to contain any deleterious materials. Although the Packerton Member forms the crest of the first ridge north of Long Run and Beaverdam Run, it does not crop out extensively along the ridge. However, the overburden along the front (south) of this ridge is probably thin in most places and quarries could be opened into the ridge at almost any place with anticipation of encountering a good source of crushed rock.

The sandstones of the Sawmill Run, Berry Run, and Clark's Ferry Members (Catskill Formation) are also potential sources of crushed rock. However, these rocks are probably less desirable for development purposes than the previously discussed units. All three of these members have a moderate content of micaceous material and moderate to well-developed parting characteristics. Well-developed bedding and related parting is not particularly desirable because of the tendency for such rock to produce flat particles. This effect can be controlled to some extent by suitable crushing procedures, but may result in increased production cost. Within the mapped area, none of these rocks occurs in a situation ideally suited for quarry development except for the Berry Run Member, which crests a fairly steep slope on the south side of Bear Mountain. The sandstones of the Sawmill Run Member are interbedded with red siltstones and selectivity in quarrying would be necessary. The Sawmill Run is a relatively weak rock unit and consequently occupies the poorest topographic position (topographic lows) for quarrying operations.

The lower part of the Spechty Kopf Formation contains a hard white quartzitic sandstone (measured section 18, unit 48) which should make an excellent high-silica crushed rock. Thin sections indicate that the rock is probably 98 percent or more silica and extremely well cemented. At Jim Thorpe the unit is 33 feet thick, but in outcrops along the Lehigh River to the north of Jim Thorpe the sandstone exceeds 50 feet in thickness. The unit possesses a well-developed parting tendency which might adversely affect its crushed shape, and nowhere in the mapped area is there a desirable quarry site in this unit. However, the unit does occur extensively to the north, in the Christmans quadrangle, where some good quarry sites exist.

## LIGHTWEIGHT AGGREGATE

No lightweight aggregate is now being produced in the mapped area and none is known to have been produced in the past. Bloating tests of a typical sample of Mahantango shale from near Harrity (O'Neill and others, 1965, p. 109-110) indicate that the shale is potentially a good lightweight aggregate, and quantities of the shale are abundant throughout much of the area. Similar tests of a Marcellus shale sample from West Bowmans (op. cit., p. 111-112) indicate that the Marcellus has very little potential as a source of lightweight aggregate. Tests of the Martinsburg shale at several localities in nearby areas (op. cit., p. 252-255; 272-281) indicate that the Martinsburg is a potential source for lightweight aggregate. Abundant supplies of this material exist in waste dumps of slate quarries as well as in unquarried rock. Clinker residues at Palmerton, described below, have been used as aggregate for cinder blocks.

Lightweight aggregate appears to have an expanding future in the construction field, particularly with the increasing demand for skid-resistant surfaces and lightweight concrete block. Other uses for this material are constantly being developed and demand may soon warrant exploitation of available shale and slate materials in the mapped area to produce lightweight aggregate. Expanded clay and shale accounted for two thirds of the total (United States) tonnage of lightweight aggregate in 1967 and expanded slate only 5 percent of the total tonnage (Rock Products, 1968, p. 65-66).

## CLINKER RESIDUE

Clinker residue from smelting operations by the New Jersey Zinc Company forms two conspicuous dumps in and near Palmerton (see Plate 2 and Figure 131). S. S. Huyett, Vice President and General Manager of Manufacturing, has described the clinker residue piles and operations at Palmerton (written commun., Nov. 1971):

> At Palmerton the Company operates zinc oxide furnaces, vertical retort metal furnaces, and electric furnaces for the production of Spiegeleisen. A portion of the spent briquets from the oxide furnaces is used currently at the metal furnaces. Granulated slag from the electric furnaces has been sold for aggregate uses but currently is being returned to the originating mine for back-fill use. Spent briquets from the metal furnaces are stored temporarily on Company land east of the East Plant. This storage comprises a fairly large area and is known locally as the "cinder bank".

> These residues all have metallurgical values and they are reworked when the reclaimable values justify this utilization. Residues which have no foreseeable reclamation value are utilized, under contract, in the manufacture of aggregates for various uses ("cinder blocks and winter non-skid" included).
>
> The quantity of material reclaimed for metallurgical values varies widely from time to time, depending upon technical developments or economic market changes. Reclamation for the production of aggregates is reasonably steady and, over the past few years, has represented about 150% of the current rate of addition to storage. A similar area exists at the east end of the West Plant, from which materials are being reclaimed but on which no new materials have been deposited for a number of years.
>
> Production rates of these spent briquets are about 40,000 tons per year at the zinc oxide operation and 120,000 tons per year at the zinc metal operation. Recent estimates of the present stocks of these materials are 3,000,000 tons of oxide furnace residues and 4,000,000 tons of metal furnace residues. Within the limits of our previous contractual commitments, these materials are available for any higher use that newly developed metallurgical technology may indicate.

The Aggregate Sales Company in Palmerton is presently using the cinders for road metal ("winter anti-skid") and cinder blocks. Some of the clinker residue is fused into large pieces and is not suitable for these products. The cinders are selectively removed and cinders less than about one inch are screened out. In 1971 about 75,000 tons of material was used and in some years about 200,000 tons has been removed.

## FILL MATERIAL

The Mahantango Formation has been quarried in a number of places as a source of road metal and fill material. None of these quarries is a continuous operation and the quantity of material produced is not large. Rather, this material is quarried mainly for occasional local use. The Mahantango shale is suitable for fill material because:

1. The joints, cleavage, and bedding result in ready breakup and easy quarrying.
2. It has moderate resistance to rapid disintegration.
3. Moderate disintegration produces some clay which results in good packing qualities.

Some fill material is quarried from the near-surface weathered part of the Mahantango Formation but more is quarried from deposits of shale-chip gravel derived from the Mahantango Formation (see section on surficial deposits). Several borrow pits have been opened in this material in the Pohopoco and Buckwha Creek valleys between the Lehigh River and the Wisconsinan terminal moraine about 16 miles to the east. The gravel is desirable primarily because it is uniform in size and is easily quarried (front end loader). Its characteristics are the same as those of the Mahantango Formation.

Fill material has also been derived from the Illinoian(?) glacial till in the Pohopoco Creek valley for use in the earth core of the Beltzville Dam. The heterogeneous nature of this material and its relatively high clay content make it very useful for impervious fill material. Numerous deposits of this till occur in the mapped area and to the east and north of the mapped area, but many of these deposits may be thin and of insufficient quantity to furnish large supplies of the material. Another disadvantage is the presence of large boulders which must be removed.

Weathered slates from the Martinsburg Formation and siltstones from the Bloomsburg Formation have been used locally for road fill. One large borrow pit in the Martinsburg is located along the east side of Pa. Route 145 about one mile north of Walnutport.

## CLAY

There are no clay deposits currently being exploited in the mapped area. However, potential clay deposits may exist at Little Gap, southeast of Bowmanstown and north of Walkton in rocks of the New Scotland Formation, Shriver Chert, and Buttermilk Falls Limestone. Clay resulting from intense leaching of these rocks has been quarried by the Universal Atlas Cement Company to the east of the mapped area near Kunkletown. This clay is used as a whitener in cement.

In the mapped area, these clay-producing rocks occur in structural settings similar to those in the Kunkletown area (plunging antiforms) and should have undergone similar weathering conditions, giving rise to clays of similar character. The presence of clay deposits in these areas is not proven, but the potential may warrant further investigation.

The character of the clays in the Kunkletown area is reported by Leighton (1934 and 1941) and detailed data on their stratigraphic and structural relations are given by Epstein and Hosterman (1969). No samples of clays were obtained in the mapped area, but the clays should be similar to those near Kunkletown, and recent analyses (on file at the Pennsylvania Geological Survey, Harrisburg) of samples from the quarries of the Universal Atlas Cement Division, U.S. Steel Corporation, are given in Table 25. Slow-firing tests (not reported here) of these clays indicate that their absorption and shrinkage is probably too high for low-duty refractory brick, but some potential for stoneware exists if large quantities of alkali are added.

At the base of the Buttermilk Falls Limestone (below the Hazard paint ore member) is a white clay which was sampled in quarries of the Alliance Sand Company at Palmerton. X-ray mineralogic analysis of this clay (analysis by Pennsylvania Geological Survey) showed the following composition:

| | |
|---|---|
| Quartz | 39% |
| Mica | 19 |
| Kaolinite | 12 |
| C-V-Mo | < 1 |
| Feldspar | < 1 |

This clay is somewhat different in composition from the Kunkletown area clay reported in Table 25 and may have considerably different

### Table 25. *Chemical Analyses, X-ray Mineralogic Analyses, and Physical Tests of Clay Samples from near Kunkletown*

Sample 1 (205–5–3) is from the New Scotland Formation 4.1 miles east-northeast of Kunkletown and sample 2 (205–5–4) is from the Buttermilk Falls Limestone 3.5 miles east-northeast of Kunkletown. NA, not available; ND, not determined.

| | Sample | |
|---|---|---|
| Chemical analysis | 1 | 2 |
| L. O. I. @ 1,000°C | 3.74% | 3.22% |
| $H_2O$ loss @ 110°C | .20 | .16 |
| Combined $H_2O$ | NA | NA |
| $SiO_2$ | 77.40 | 78.90 |
| $Al_2O_3$ | 12.30 | 12.00 |
| $Fe_2O_3$ | .94 | .70 |
| FeO | ND | ND |
| CaO | .06 | .08 |
| MgO | .75 | .64 |
| $CO_2$ | .13 | .15 |
| $Na_2O$ | .30 | .21 |
| $K_2O$ | 3.63 | 3.50 |
| $TiO_2$ | .85 | .73 |
| $P_2O_5$ | NA | NA |
| MnO | NA | NA |
| S (total) | > .03 | .04 |
| C (total) | .09 | .14 |
| | Sample | |
| X-ray mineralogic analysis | 1 | 2 |
| Quartz | 49.0 | 50.0 |
| Mica | 33.0 | 30.0 |
| Kaolinite | 10.0 | 14.0 |
| C-V-Mo | .0 | .0 |
| Feldspar | 2.0 | 1.0 |
| Physical tests | | |
| pH | 4.82 | 5.05 |
| P. C. E. | 23–24 | 24–25 |
| Water of plasticity | 27.1 | 27.9 |
| Drying shrinkage | .5 | 2.5 |
| Dry strength | Fair | Fair |

properties, but it has not been tested. The clay occurred in all the paint ore mines reported by Hill (1887, p. 1393-1400) and was generally 4 feet or more in thickness. The distribution of this clay is presumably the same as the rest of the Buttermilk Falls Limestone. Further tests are necessary to prove the clay an economic resource.

A clay sometimes develops through weathering of shale at the base of the Schoharie-Esopus Formation. An X-ray mineralogic analysis (analysis by Pennsylvania Geological Survey) of a sample from this horizon in the Universal Atlas quarries near Kunkletown gives the following composition:

| | |
|---|---|
| Quartz | 29% |
| Mica | 50 |
| Kaolinite | 18 |
| C-V-Mo | 0 |
| Feldspar | 0 |

Nothing is known about the properties, potential use or degree of development of this clay.

Two clay deposits of limited quantity occur in surficial deposits in the mapped area. One deposit is a red clay which sometimes occurs as thin beds in Illinoian(?) outwash deposits along Pohopoco Creek (see section on surficial deposits). The X-ray mineralogic composition of one of these clays is presented on page 215. The fresh clay is plastic, but no use tests have been made for it. The quantity of clay available is unknown and all known occurrences of this clay are under water in the Beltzville reservoir.

The other deposit occurs along Pa. Route 443 just west of Lehighton and is probably deeply leached clay-rich Illinoian(?) till. The X-ray mineralogic composition of this material is presented in the section on surficial deposits. The clay has been used locally as a sealer in ponds. No other deposit of similar material was observed in the mapped area.

## HYDRAULIC CEMENT

True hydraulic cements have been in use since ancient Roman times. Although there are several varieties of hydraulic cement, one of the common types results from calcination and grinding of impure limestone such as in the Buttermilk Falls Limestone. The use of such cements has largely been replaced by Portland cement. Early in the nineteenth century hydraulic cement was produced from a quarry located below the processing plant of the Alliance Sand Company northeast of Hazard. According to Chance (1882b, p. 355) the cement was of superior quality and "all the masonry of the Lehigh and Susquehanna canal was laid with it, and the way it has worn certainly does not condemn it."

There are no reported chemical analyses of the limestone used for production of the Carbon County hydraulic cement and none were made during this investigation.

The "Onondaga" "cement bed" occurred in all the paint-ore mines reported by Hill (1887, p. 1391-1400) and apparently occurs above the Palmerton Formation throughout the mapped area. However, the limestone is almost totally unexposed in the area and thus available only through extensive mining.

There is currently little demand for hydraulic cement and without an extensive local market the available hydraulic cement resource in the mapped area will probably remain only a potential because of the relatively high production cost (due to the necessity for mining) and the cost of transportation to more distant markets.

## ROOFING GRANULES

Roofing granules are rock particles placed on top of felt and asphalt roofs to protect the roofs from the sun's rays. The granules are usually ⅛ to ¾ inch in diameter, but rocks as large as 4 inches have been used for artistic effect. Physical specifications require mainly that the granules be dry and free of fines and dust so they will stick well to hot asphalt. The granules must be hard enough to resist breakage and dust production during handling and transportation. Angular particles are preferred because of better packing with a minimum of open space between grains. An even size distribution through the size range is best for optimum coverage and opaque granules best protect the asphalt from deterioration from the sun's rays, as well as partly fireproof the asphalt.

Some of the red siltstones and fine-grained sandstones of the Walcksville and Long Run Members (Catskill Formation) and the Mauch Chunk Formation would be suitable for production of red granules. Green granules could be produced from some of the green siltstones of the Walcksville Member (Catskill Formation). The Beaverdam Run Member (Catskill Formation) would produce a pleasant brownish-gray granule. As mentioned above, waste slate from the Martinsburg Formation may also be used for the production of granules.

## HYDROCARBONS

"The Appalachian basin includes the area in which the modern petroleum industry started. Its oil and gas fields have had the longest production history of any on the North American continent. Their commercial development dates from the discovery of oil in a stray sand of Upper Devonian age at a depth of 69 feet in the Drake well along Oil

Creek south of Titusville in northwestern Pennsylvania in 1859." (Fettke, 1953, p. 11). The easternmost subsurface exploration for hydrocarbons, specifically natural gas, in the Appalachian basin of Pennsylvania began in earnest in the mid-1950's.

In 1950, Willard and Stevenson called attention to probabilities of hydrocarbons in northeastern Pennsylvania and central New York. They described the presence of folds, unconformities, reefs or bioherms, lateral and vertical transitions in sedimentary rocks, regional thickness changes, and source- and reservoir-type beds. They observed (p. 2282): "the area of northeastern Pennsylvania and adjacent parts of central New York has potentialities worth recording for future use in the search for petroleum and natural gas."

In 1956, gas discovery and development occurred in Lackawanna County in the Richards #1 well drilled by Transcontinental Production Company. This discovery well is situated 100 miles east of any well producing at that time and only 4 miles from the edge of the anthracite coal fields of the Lackawanna basin (Grow, 1964). The "pay" zone occurred below the top of the Upper Devonian Trimmers Rock Formation and, as illustrated by Grow (Figure 4, p. 81), many shows of gas were observed at various stratigraphic horizons within the Upper Devonian in several of the wells drilled in this Harvey Lake gas field.

Discovery of the Harvey Lake gas field spurred extensive leasing and wildcat drilling by major petroleum companies in the northeastern counties of Pennsylvania. Wietrzychowski (1963a) lists 31 known wells penetrating the Upper Devonian and deeper rocks in northeastern Pennsylvania. His map (op. cit., p. 44) has been updated to January, 1969 to include three new-field wildcats drilled since 1963 (Graver Estate #1, Carbon County; Lally #1, Lackawanna County; Hudson Realty #1, Wayne County). Wagner (1963) discussed the history of gas exploration in northeastern Pennsylvania from 1930 to 1963.

During the early stages of mapping in the Lehighton-Palmerton-Jim Thorpe area two exploratory wells were drilled on the Lehighton anticline in Towamensing Township near the western border of the mapped area (Plate 1). In August, 1962, Pure Oil Company completed, plugged, and abandoned the Harvey Smith #1 (Lytle and others, 1963). The well was dry and bottomed in the Onondaga Formation (Buttermilk Falls Limestone in this report) at a depth of 3,211 feet.

A second well, the Graver Estate #1, also dry, was completed in September, 1964, by Phillips Petroleum Company. The well was plugged and abandoned at 5,385 feet in the Upper Silurian Wills Creek-Tonoloway Formations (Lytle and others, 1965). The description of the cuttings from this well, taken from Geological Sample Log Company data for the well, is presented as section 24 in the Appendix.

Assuming that both the Smith and Graver wells were Oriskany (Ridgeley Formation) tests, data furnished in this report (Plate 1) show that it is reasonable to expect that the Oriskany is nearest the surface at Weissport where the Marcellus Formation is exposed and the Oriskany should occur less than 1,000 feet below the surface.

No exploration has yet occurred in the Upper Devonian sedimentary rocks of Carbon County. Rocks of similar age were productive in the Harvey Lake gas field described earlier. There is sufficient structural complexity associated with probable subsurface facies changes along the northern border of the mapped area as well as to the north and northeast that hydrocarbon potential in the Trimmers Rock and Catskill Formations cannot be dismissed without judicious exploration. As observed by Grow (1964), the sedimentologic and stratigraphic relationships in the Upper Devonian rocks were of prime importance in the Harvey Lake gas field and structure alone had little bearing upon gas accumulation.

## METALLIC MINERALS

Minor occurrences of several metallic minerals in the mapped area have been reported by Klemic and others (1963, p. 90-91) and include galena, sphalerite, chalcopyrite, malachite, and uranium (probably occurring as uraninite). All of these minerals except uranium occur in the Trimmers Rock Formation at Walcksville.

Uranium has been reported in the Jim Thorpe area by a number of workers (Wherry, 1915; Dyson, 1954; Montgomery, 1954; Klemic and Baker, 1954; McCauley, 1961; Klemic, 1962; and Klemic and others, 1963). One occurrence is in the lower part of the Duncannon Member of the Catskill Formation along the railroad south of Jim Thorpe on the west side of the Lehigh River. Another occurrence is in the upper part of the Clark's Ferry Member of the Catskill Formation along U.S. Route 209 south of Jim Thorpe. A third occurrence is in the basal conglomeratic beds of the Mauch Chunk-Pottsville transition zone which crops out along U.S. Route 209 north of Jim Thorpe. Some test mining of this deposit has been done and further drilling exploration was carried out during the summer of 1969, but no commercial uranium has been removed to date. The potential worth of these uranium deposits is not known, but active investigation of these deposits recommenced in 1973.

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# APPENDIX I. DESCRIPTION AND EVALUATION OF WHITE'S TYPE SECTIONS

by J. D. Glaeser

## DESCRIPTION OF WHITE'S TYPE SECTIONS

Forty-two outcrops were measured and described in detail by the writer at White's (1881) seven type locations (Figure 174). The purpose of the reexamination was to (1) tabulate lithologic properties of exposures at each type location (specifically grain size, color, bedding properties, primary sedimentary structures and fossils), and (2) to compare rocks at White's (1881) type locations with the Catskill rocks at the Lehigh River.

Figure 175 shows the detailed measurements and descriptions of the exposures at White's (1881) type locations. One of the most important observations at these sections is the occurrence of fining-upward cycles at Honesdale and Cherry Ridge. Similar, though less abundant, cycles were observed at Elk Mountain. Also important at the type locations is the areally widespread occurrence of lenticular zones of calcareous material.

## EVALUATION OF WHITE'S TYPE SECTIONS AND THEIR RELATIONSHIP TO THE LEHIGH RIVER SECTION

### Starrucca

White (1881, p. 70) named the lowermost Catskill beds "Starrucca" for exposures near that town (Figure 174). He applied the name to "olive or greenish shales (which) contain numerous thin sandstones . . . and topped in some places with one or more massive." At the Lehigh River, he observed "greenish-gray flaggy sandstone," (1882, p. 80) the base of which lay 120 feet below the lowest red bed there (p. 80 and 103). He correlated the rocks from Starrucca with this unit.

The newly examined exposures around Starrucca are most easily relatable to the physical attributes of the unit which the present writer calls the Towamensing Member at the Lehigh River (Figure 101). This locally defined member has the same limits as White's Starrucca unit at the Lehigh River (White, 1882). Because mapping has not yet demonstrated relationships of these rocks between the Lehigh River and Starrucca, a name from the Lehigh River valley is used here. However, should a

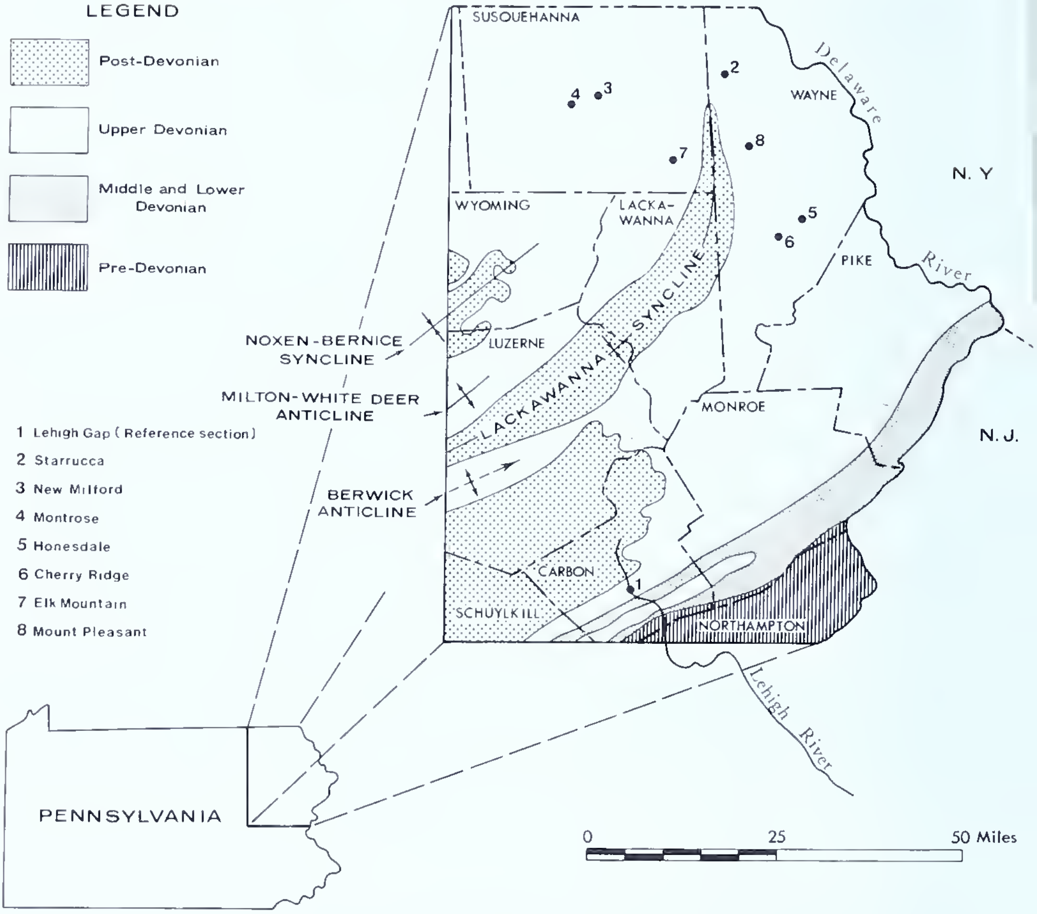

Figure 174. Type locations of I. C. White's (1881) Catskill members.

future correlation be proven by detailed field mapping, the name Towamensing should be abandoned in favor of the name Starrucca.

## New Milford and Montrose

White (1882, p. 101) assumed the New Milford shale to be the first re horizon above the base of the Catskill Formation (Figure 175). Separating the New Milford from the Montrose, also red, White (p. 99) suggeste that a sandstone, which he called the Delaware River Flags, occurred t the southeast of his New Milford and Montrose type sections.

There is no difference in the outcrop characteristics at New Milfor and Montrose, no major sandstone between these two type locations, and little similarity between rocks at Montrose and the unit which Whit (1882) called Montrose at the Lehigh River section.

The writer (Glaeser) suggests that all physical properties observed a sections around both New Milford and Montrose clearly relate these

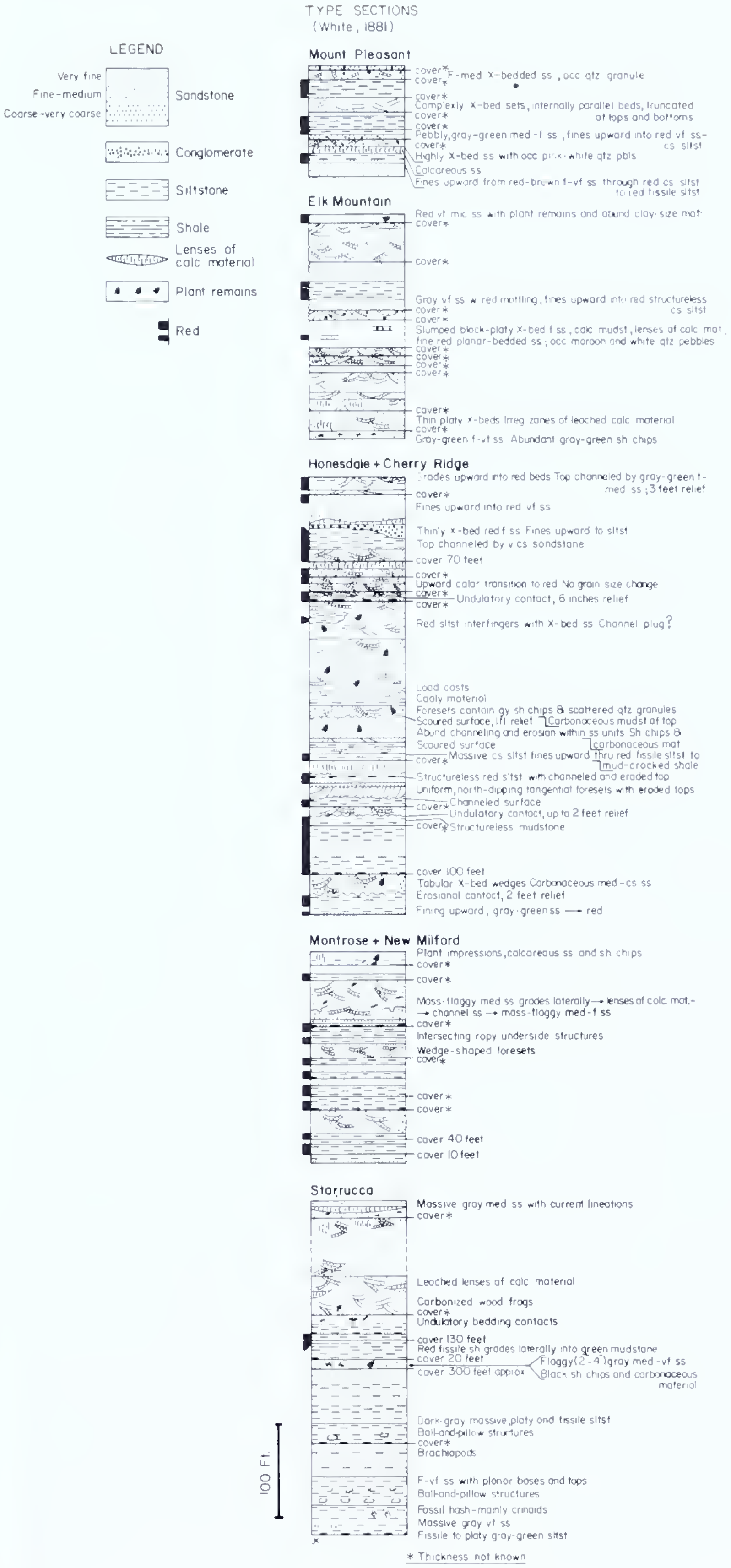
TYPE SECTIONS
(White, 1881)
LEGEND
Very fine
Fine-medium
Coarse-very coarse
Sandstone
Conglomerate
Siltstone
Shale
Lenses of calc material
Plant remains
Red
Mount Pleasant
cover*
F-med x-bedded ss, occ qtz granule
cover*
cover*
Complexly x-bed sets, internally parallel beds, truncated at tops and bottoms
cover*
cover*
Pebbly, gray-green med-f ss, fines upward into red vf ss-cs sltst
cover*
Highly x-bed ss with occ pink-white qtz pbls
Calcareous ss
Fines upward from red-brown f-vf ss through red cs sltst to red fissile sltst
Elk Mountain
Red vf mic ss with plant remains and abund clay-size mat
cover*
cover*
Gray vf ss w red mottling, fines upward into red structureless cs sltst
cover*
cover*
Slumped block-platy x-bed f ss, calc mudst, lenses of calc mat, fine red planar-bedded ss; occ maroon and white qtz pebbles
cover*
cover*
cover*
cover*
cover*
Thin platy x-beds Irreg zones of leached calc material
cover*
Gray-green f-vf ss Abundant gray-green sh chips
Honesdale + Cherry Ridge
Grades upward into red beds Top channeled by gray-green f-med ss; 3 feet relief
cover*
Fines upward into red vf ss
Thinly x-bed red f ss Fines upward to sltst
Top channeled by v cs sandstone
cover 70 feet
cover*
Upward color transition to red No grain size change
cover*
Undulatory contact, 6 inches relief
cover*
Red sltst interfingers with X-bed ss Channel plug?
Load casts
Coaly material
Foresets contain gy sh chips & scattered qtz granules
Scoured surface, 1ft relief
Carbonaceous mudst at top
Abund channeling and erosion within ss units Sh chips & carbonaceous mat
Scoured surface
cover*
Massive cs sltst fines upward thru red fissile sltst to mud-cracked shale
Structureless red sltst with channeled and eroded top
Uniform, north-dipping tangential foresets with eroded tops
Channeled surface
cover*
Undulatory contact, up to 2 feet relief
cover*
Structureless mudstone
cover 100 feet
Tabular X-bed wedges Carbonaceous med-cs ss
Erosional contact, 2 feet relief
Fining upward, gray-green ss → red
Montrose + New Milford
Plant impressions, calcareous ss and sh chips
cover*
cover*
Mass-flaggy med ss grades laterally → lenses of calc mat. → channel ss → mass-flaggy med-f ss
cover*
Intersecting ropy underside structures
Wedge-shaped foresets
cover*
cover*
cover*
cover 40 feet
cover 10 feet
Starrucca
Massive gray med ss with current lineations
cover*
Leached lenses of calc material
Carbonized wood frags
cover*
Undulatory bedding contacts
cover 130 feet
Red fissile sh grades laterally into green mudstone
cover 20 feet
Flaggy (2"-4") gray med-vf ss
cover 300 feet approx
Black sh chips and carbonaceous material
Dark-gray massive, platy and fissile sltst
Ball-and-pillow structures
cover*
Brachiopods
F-vf ss with planar bases and tops
Ball-and-pillow structures
Fossil hash-mainly crinoids
Massive gray vf ss
Fissile to platy gray-green sltst
100 Ft.
* Thickness not known

Figure 175. Newly measured sections at I. C. White's (1881) original type Catskill localities.

lithologies to the Walcksville Member (Klemic and others, 1963) at the Lehigh River section (Figure 101). This interpretation suggests that rocks at these widely spaced locations are the products of a similar depositional regime and that White's (1882) separation of the New Milford and Montrose at the Lehigh section is not justified on the basis of lithologic evidence.

## Honesdale and Cherry Ridge[1]

Figure 175 gives the details of the newly measured sections at Honesdale and Cherry Ridge.

Seven fining-upward cycles were identified in outcrops around Honesdale and Cherry Ridge. Cycles similar to these have been observed at the Lehigh River section in the upper part of the Long Run Member. The upper parts of the Long Run Member are similar to rocks at Honesdale and Cherry Ridge and the correlation is made, therefore, with the Long Run.

This suggested relationship between rocks at Honesdale and Cherry Ridge with rocks of the upper Long Run Member at the reference section is considerably lower stratigraphically than White's (1882) selections of units at the Lehigh River.

## Elk Mountain and Mount Pleasant[2]

Up to 200 feet of "gray, red, green and spotted shales with a few sandstone layers" were assigned by White (1881, p. 64) to the Elk Mountain Member of the Catskill Formation. Elsewhere he called this interval the "Elk Mountain green sandstones and shales" (1882, p. 95). He thought that he recognized the interval near the top of the Catskill Formation along the Lehigh River.

At Mount Pleasant, White (1881, p. 63) observed 100 feet of red shale and elsewhere (1882, p. 79 and 95) he assigned the same name to red conglomerates, sandstones, and shales.

In Mount Pleasant Township, the sequence of exposures examined by the writer has essentially the characteristics observed in outcrops at Elk Mountain, although more of the rock in Mount Pleasant Township is red.[1] However, the stratigraphic relationships between these two type locations straddling the Lackawanna syncline cannot be interpreted with present data.

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[1] No exposures occur at Cherry Ridge, although new roadcuts east of the town just south of Honesdale pass through beds stratigraphically higher than any described by White (1881).

[2] The town is now called Pleasant Mount and the township in which it is located retains the original name.

Sand grain size, presence of conglomeratic sandstones, abundant leached calcareous zones, crossbedding, and minor red color at Elk Mountain exposures imply a relationship in depositional origin of these rocks and those described by the writer as the Packerton, Sawmill Run, and Berry Run Members at the Catskill section on the Lehigh River (Figure 101). The presence of red beds, conglomeratic and calcareous sandstones, leached calcareous zones, and abundant crossbedded sandstones at outcrops observed in Mount Pleasant Township suggests that these rocks are also most similar to the Packerton, Sawmill Run, and Berry Run Members at the Lehigh River.

Note that the parts of the reference section to which Elk Mountain and Mount Pleasant rocks seem to best fit (Figure 175) are below the uppermost two members at the Lehigh River section, which are not accounted for lithologically at any of White's (1881) type locations. Rocks comprising these upper two members of White (1882) at the Lehigh River differ lithologically from rocks observed at the type locations from which the names were derived (Mount Pleasant, Elk Mountain, and Cherry Ridge).

It might be suggested that these uppermost 2,000 feet of coarse clastics at the Lehigh River section are related laterally to units of White's highest type members and that a direct comparison of lithologic assemblages does not adequately account for lateral changes which might occur, since intermediate sections have not been used to support the writer's comparisons. Reconnaissance investigations do not support this contingency. These coarse clastics have been found in areas other than those around White's (1881) type sections; they were observed in Wayne and Pike Counties and occur in what this writer (Glaeser) thinks are gentle synclinal structures similar to those described elsewhere in northeastern Pennsylvania by Fletcher and Woodrow (1970). No detailed study or map of the extent and shape of these structures has been made by the writer.

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[1] Red beds cap South Knob at Elk Mountain and typical Catskill gray-green, crossbedded, medium- to fine-grained sandstones with interbedded siltstones cap North Knob. No lithology typical of the Pocono was observed (Glaeser, 1968). The geologic map of Pennsylvania (Gray and others, 1960) indicates that both knobs are Pocono Formation.

# APPENDIX II. MEASURED SECTIONS

## SECTION 1

### PARTS OF POXONO ISLAND FORMATION AND BOSSARDVILLE LIMESTONE

Parts of the Poxono Island Formation and Bossardville Limestone exposed along tracks of the Central Railroad of New Jersey, 3,500 feet southeast of intersection of Pa. Routes 895 and 248 in Bowmanstown. Beds are vertical. Section measured by J. B. Epstein.

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| *Bossardville Limestone (part)* | | |
| 15 | Limestone, medium-dark-gray (N4) to medium-gray (N5), quartzose, very fine to fine-grained. Very fine grained beds are argillaceous. Finely bedded to laminated; unevenly to wavy bedded. Beds range from thin laminae to 2 in. thick. Minor ostracodes. Upper and lower contacts covered. | 1.8 |
| 14 | Covered; float consists of medium-dark-gray (N4) fine-grained limestone containing abundant ostracodes. | 5.7 |
| 13 | Limestone, medium-dark-gray (N4), to medium-gray (N5), fine- to very fine grained; weathers yellowish gray (5Y8/1) to pale-yellowish brown (10YR6/2) and light gray (N7); laminated to finely bedded, beds as much as 3 in. thick, fine-grained beds less than 0.5 in. thick; graded; basal parts of some beds quartzose and stand out in relief upon weathering. | 1.4 |
| | Incomplete thickness of Bossardville Limestone. | 8.9 |
| *Poxono Island Formation (part)* | | |
| 12 | Dolomite, greenish-gray (5GY6/1), partly calcareous; weathers dark-yellowish orange (10YR6/6); partly argillaceous and mud cracked; burrow mottled and indistinctly bedded; basal contact abrupt. | 4.3 |
| 11 | Partly covered; calcareous dark-yellowish-orange (10YR6/6) to pale-yellowish-orange (10YR8/6) weathered dolomite in float. | 1.8 |
| 10 | Limestone and calcareous shale. Medium-gray (N5) very fine to fine-grained limestone interlaminated with and partly grading up into irregular laminae of greenish-gray (5GY6/1) calcareous shale; mud cracked. Basal contact gradational. | 1.3 |
| 9 | Similar to unit 10 but without mud cracks. Basal contact gradational. | 3.5 |
| 8 | Limestone, medium-dark-gray (N4) to medium-gray (N5), fine- to very fine grained, partly argillaceous; laminated to finely bedded; graded, some basal beds are quartzose and stand out in relief upon weathering; some laminae lenticular; scattered micro-channeling; minor burrows; ostracodes concentrated in basal part of graded bed; rare intraclasts as much as 0.5 mm long. Basal contact abrupt. | 1.8 |
| 7 | Calcareous dolomite, quartzose limestone, and shale. Light-bluish-gray (5B7/1) laminated calcareous dolomite in laminae and beds as much as 0.5 in. thick, medium-gray (N5) limestone laminae averaging about 0.1 in. thick, and greenish-gray (5GY6/1) paper-thin shale. Graded; mud cracked; ostracodes in basal coarser beds; fillings between mud cracks composed of greenish-gray (5GY6/1) dolomitic shale as much as 0.25 in. thick. | 0.8 |
| 6 | Shale and dolomite. Mud-cracked greenish-gray (5GY6/1) to pale-olive (10Y6/2) calcareous indistinctly bedded and laminated shale which grades up into greenish-gray (5GY7/1) calcareous dolomite which weathers grayish orange (10YR7/4) to dark-yellowish orange (10YR6/6). | 4.5 |
| 5 | Covered. | 6.5 |
| 4 | Shale and limestone. Medium-gray (N5) and pale-olive (10Y6/2) pyritic calcareous shale in laminae and beds as much as 5 in. thick, interbedded with very fine to medium-grained, unevenly bedded and laminated, graded (fine-grained calcarenite and calcisiltite with ostracodes grading up into micrite), partly quartzose limestone in beds as much as 0.75 in. thick and greenish-gray (5GY6/1) to grayish-green (10GY5/2) calcareous shale from laminae to 0.5 in. thick. | 4.0 |
| 3 | Limestone and shale. Medium-light-gray (N6) to medium-gray (N5) very fine to fine-grained pyritic limestone which weathers light gray (N7) to medium-light gray (N6) in laminae and beds 0.05 to 0.5 in. thick and containing ostracodes, interbedded and interlaminated with medium-light-gray (N6) calcareous shale to argillaceous limestone which weathers grayish orange (10YR7/4). A few thin (less than 0.25 in.) beds of very fine grained quartzose calcarenite and calcareous sandstone at base of graded units. Some calcareous shale intraclasts as much as 1.5 in. long in coarser beds. Some beds have micro scour-and-fill. | 1.3 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 2 | Limestone, silty, pyritic, medium-light-gray (N6), fine- to medium-grained; unevenly bedded and laminated; partly graded; beds less than 0.25 to 2 in. thick and are separated by paper-thin light-gray (N7) to medium-light-gray (N6) calcareous shale which weathers dark-yellowish orange (10YR6/6); some beds contain limestone intraclasts as much as 0.75 in. long; abundant leperditiid and ornate ostracodes and some brachiopods in limestone beds. | 1.2 |
| 1 | Covered; greenish-gray (5GY6/1) shale float. | Not measured |
|  | Incomplete thickness of Poxono Island Formation. | 31.0 |

## SECTION 2

# PARTS OF BOSSARDVILLE LIMESTONE AND DECKER FORMATION

Parts of the Bossardville Limestone and Decker Formation in abandoned quarry, 1,500 feet northeast of the Hazard School in Palmerton. Beds dip moderately northwest. Section measured by J. B. Epstein.

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| *Decker Formation (part)* |  |  |
| 20 | Siltstone, shale, and sandstone. Medium-gray (N5) to medium-light-gray (N6) slightly calcareous silty shale in uneven laminae and beds as much as 3 in. thick, and dark-yellowish-orange (10YR6/6) to greenish-gray (5GY6/1) slightly calcareous, leached, fossiliferous, moderately to extensively burrowed, micro cross-laminated and unevenly parallel laminated, and lenticular siltstone to fine-grained sandstone (fossils include favositids, crinoid columnals, and brachiopods—many *Eccentricosta jerseyensis* on some bedding planes). Lower contact abrupt; upper boundary covered by debris from sand quarry above. | 10.7 |
| 19 | Calcareous siltstone to very fine grained sandstone and arenaceous limestone; weathers grayish orange (10YR7/4); massively bedded, beds as much as 3.5 ft. thick, partly laminated, extensively burrowed, small-scale cut-and-fill structure, abundant fossils (bryozoans and brachiopods including *Eccentricosta jerseyensis*) give rock a straticulate appearance; basal contact abrupt. | 8.7 |
| 18 | Shale and siltstone, calcareous, contains very fine sand, medium-dark-gray (N4) silty shale (about 10 percent of unit) interlaminated and interbedded with greenish-gray (5GY6/1) calcareous shaly siltstone which weathers dark-yellowish orange (10YR6/6) to grayish orange (10YR7/4); beds ¼ to 3 in. thick. Abundant ostracodes. | 2.1 |
| 17 | Limestone and shaly limestone. Medium-gray (N5) to medium-dark-gray (N4) very fine to medium-grained limestone which weathers medium-light gray (N6) to medium gray (N5), interlaminated and interbedded (beds as much as ¾ in. thick) with greenish-gray (5GY6/1) shaly limestone which weathers grayish orange (10YR7/4). Slightly dolomitic. Coarser limestone contains minor medium- to very coarse grained quartz sand. Some laminae with numerous ostracodes and lesser brachiopod, bryozoan, and gastropod fragments. Some laminae disrupted, producing intraclasts as much as 5 in. long. Many laminae and beds graded from sandy ostracode-rich medium-grained limestone at base to very fine grained shaly limestone at top. Stromatolitic in places (hemispheroids of low relief as much as 8 in. in diameter to crinkly laminated sheets). | 1.0 |
| 16 | Siltstone, coarse, sandy, calcareous, moderate-brown (5YR3/4-5YR4/4), leached, platy. | 0.8 |
| 15 | Limestone, medium-dark-gray (N4), very fine to fine-grained, slightly uneven beds ½ to 4 in. thick, intraclasts, oolitic. Very abundant ostracodes, lesser bryozoans, brachiopods, and rare conodonts. | 1.5 |
| 14 | Limestone, siltstone, and shale. Medium-dark-gray (N4) fine- to coarse-grained silty limestone which weathers medium-light gray (N6) and light-bluish gray (5B7/1) interlaminated and interbedded with greenish-gray (5GY6/1) calcareous and partly arenaceous siltstone and shale which weathers grayish orange (10YR7/4). Laminae parallel and irregular. Many ostracodes, some brachiopods and stromatolite hemispheroids of low relief as much as 1 in. in diameter. Many beds and laminae graded. | 0.9 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 13 | Limestone, silty to finely arenaceous, and calcareous siltstone, medium-gray (N5) to medium-light-gray (N6), weathers yellowish brown (10YR5/4), partly leached, abundant ostracode fragments, irregularly laminated to micro cross-laminated. Contact with underlying Bossardville Limestone placed at the base of the lowest calcareous siltstone or sandstone. | 0.3 |
| | Incomplete thickness of Decker Formation. | 26.0 |
| *Bossardville Limestone (part)* | | |
| 12 | Limestone and shale. Medium-dark-gray (N4) quartzose pyritic fine- to coarse-grained limestone which weathers medium-light gray (N6) and light-bluish gray (5B7/1) interlaminated and finely interbedded with greenish-gray (5GY6/1) calcareous and partly dolomitic shale which weathers grayish orange (10YR7/4). Laminae parallel and irregular. Coarser limestone contains abundant ostracodes and intraclasts of shale and minor Bryozoa. Graded. | 2.0 |
| 11 | Covered. Float consists of laminated ostracode-rich very fine to fine-grained medium-gray (N5) to medium-dark-gray (N4) limestone and light-olive-gray (5Y6/1) calcareous shale. | 7.7 |
| 10 | Limestone and shale. Limestone, argillaceous, medium-dark-gray (N4) to dark-gray (N3), very fine to medium-grained, scattered to abundant ostracode fragments, graded, irregularly laminated with light-olive-gray (5Y6/1) calcareous shale. Lower contact abrupt. | 0.5 |
| 9 | Limestone, medium-dark-gray (N4) to medium-light-gray (N6) and light-olive-gray (5Y6/1), predominantly fine grained, laminated, many laminae disrupted, intraclasts as much as 1 in. long, many of which are encrusted with bryozoans and possibly algae (oncolites). Abundant ostracodes. Minor thin laminae of grayish-orange (10YR7/4)-weathering calcareous shale. Lower contact gradational. | 2.6 |
| 8 | Similar to unit above but with many more bryozoan-encrusted intraclasts and possibly oncolites that stand out in relief upon weathering. | 1.0 |
| 7 | Limestone, dark-gray (N3) to medium-dark-gray (N4), very fine to very coarse grained, weathers medium-light gray (N6); floating calcite grains as much as 2 mm in diameter; beds wavy and 0.75 to 4 in. thick; abundant ostracodes and bryozoans; many intraclasts as much as 1 in. in diameter with encrusting bryozoans and possibly encrusting algae (oncolites) that stand out in relief. | 2.1 |
| 6 | Limestone and shaly limestone. Medium-dark-gray (N4), very fine grained limestone which weathers light gray (N7); ostracodes; interlaminated with medium-dark-gray (N4) to medium-olive-gray (5Y5/1) shaly limestone which weathers light-olive gray (5Y6/1). Laminae less than 1 mm to 10 mm thick ("ribbon limestone"). | 1.7 |
| 5 | Limestone, argillaceous, dark-gray (N3), disrupted laminae and fine bedding, intraclasts, ostracodes. Units 5–20 exposed on the north side of quarry. | 0.4 |
| 4 | Covered across floor of quarry. | 31.0 |
| 3 | Limestone, medium-dark-gray (N4) and medium-gray (N5); laminated, some laminae shaly and silty; pyritic; weathers pale-grayish orange (10YR7/3) and medium-light gray (N6); rare ostracodes; minor burrow mottles; mud-crack columns 3–10 in. wide; paper-thin dark-gray (N3) to medium-dark-gray (N4) shale fills cracks. | 2.0 |
| 2 | Limestone, medium-dark-gray (N4), very fine grained, argillaceous, pyritic; weathers yellowish gray (5Y8/1) to moderate-yellowish brown (10YR5/4); laminated; graded; mud cracks 2–5 in. wide; rare ostracodes; scattered burrow mottles. | 2.3 |
| 1 | Covered. Float consists of medium-dark-gray (N4) laminated shaly limestone. No float seen south of unit. | 10.0 |
| | Incomplete thickness of Bossardville Limestone. | 63.3 |

## SECTION 3

## PARTS OF THE DECKER FORMATION AND POSSIBLY THE STORMVILLE MEMBER OF THE COEYMANS FORMATION

Measured section of parts of the Decker Formation and possibly the Stormville Member of the Coeymans Formation exposed in a pavement outcrop in the parking lot of Scranton Lamp Shade Company, 5,500 feet east of Ashfield. Beds dip 57° SE, overturned. Many sedimentary structures have been obliterated by deep weathering and complete leaching of calcium carbonate, and identification of stratigraphic units is open to some speculation. Rocks in units 11–14 are similar to the Andreas Red Beds described by Swartz and Swartz (1941) at Andreas, Pennsylvania, 6 miles to the southwest. Provisionally, these rocks are included in the Decker Formation, and the units above are assigned to the Stormville Member of the Coeymans Formation. See text for details on these identifications. Section measured by J. B. Epstein.

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| *Stormville Member of Coeymans Formation (part)* | | |
| 22 | Shale, siltstone, and very fine to medium-grained sandstone, variegated. Weathered to clay in places. Poorly exposed. Float of white chert from hill to northwest. | 14.7 |
| 21 | Sandstone, grayish-orange (10YR7/4) to light-brown (5YR5/6), medium-grained with some very coarse grains. Partly covered. | 4.5 |
| 20 | Sandstone, moderate-reddish-orange (10R6/6) to moderate-reddish-brown (10R4/6), very fine to medium-grained. | 2.5 |
| 19 | Sandstone, quartzose, moderate-orange-pink (5YR8/4), medium- to coarse-grained with scattered quartz grains as much as 5 mm long. | 1.0 |
| 18 | Sandstone, moderate-reddish-brown (10R4/6) to grayish-red (5R4/2), very fine to very coarse grained. Very porous, presumably due to leaching of calcium carbonate. | 3.8 |
| 17 | Sandstone, light-brown (5YR5/6), fine- to medium-grained. | 1.1 |
| 16 | Sandstone, dark-yellowish-orange (10YR6/6) to grayish-red (5R4/2), very fine to very coarse grained; conglomeratic, quartz pebbles as much as ½ in. long. Very porous, presumably because of leaching of calcium carbonate. | 1.7 |
| 15 | Sandstone, light-brown (5YR5/6), fine- to medium-grained. | 2.2 |
| | Incomplete thickness of Stormville Member of Coeymans Formation. | 31.5 |
| *Decker Formation (part)* | | |
| 14 | Shale and siltstone, pale-red (5R6/2) to grayish-red (5R4/2). Possibly top bed of Andreas Red Beds of Swartz and Swartz (1941). | 5.2 |
| 13 | Sandstone, grayish-orange (10YR7/4) to moderate-brown (5YR4/4), medium- to very coarse grained, conglomeratic, pebbles as much as ¼ in. long. | 0.8 |
| 12 | Sandstone, very fine to coarse-grained, and siltstone, pale-red (5R6/2) (hematitic) and light-brown (5YR5/4). Partly burrowed. | 12.1 |
| 11 | Sandstone, pale-red (10R6/2) to pale-reddish-brown (10R5/4), hematitic, very fine grained. Possibly lowest beds of Andreas Red Beds of Swartz and Swartz (1941). | 2.9 |
| 10 | Covered. | 5.7 |
| 9 | Siltstone to very fine grained sandstone, moderate-reddish-orange (10R6/6) to moderate-reddish-brown (10R4/6). Numerous molds of ostracodes(?) and brachiopods (*Eccentricosta jerseyensis?*). | 2.3 |
| 8 | Siltstone, shale, and very fine grained sandstone, pale-yellowish-orange (10YR8/6) to dark-yellowish-orange (10YR6/6) and pale-reddish-brown (10R5/4), minor medium-grained sandstone, kloedenid ostracodes. | 4.9 |
| 7 | Sandstone, light-brown (5YR6/4) and grayish-red (10R4/2), very fine to fine-grained. | 0.7 |
| 6 | Shale and siltstone, dark-yellowish-orange (10YR6/6), light-brown (5YR5/6), moderate-reddish-brown (10R4/6), and very dark red (5R2/6), with scattered ostracodes. | 10.0 |
| 5 | Sandstone, dark-yellowish-orange (10YR6/6) to pale-yellowish-orange (10YR8/6) and light-brown (5YR5/6) with scattered quartz grains as much as 1 mm long. | 1.1 |
| 4 | Shale and siltstone, dark-yellowish-orange (10YR6/6), light-brown (5YR5/6), moderate-reddish-brown (10R4/6), and very dark red (5R2/6), sandy, with scattered ostracodes. | 5.0 |
| 3 | Sandstone, dark-yellowish-orange (10YR6/6) to pale-yellowish-orange (10YR8/6) and light-brown (5YR5/6), argillaceous, with scattered quartz grains as much as 2 mm long. | 0.3 |
| 2 | Shale, siltstone, and lesser very fine grained sandstone, dark-yellowish-orange (10YR6/6), light-brown (5YR5/6), moderate-reddish-brown (10R4/6), and very dark red (5R2/6). | 3.6 |
| 1 | Sandstone, dark-yellowish-orange (10YR6/6) to moderate-yellowish-brown (10YR5/4), very fine to fine-grained, brachiopod molds (*Eccentricosta jerseyensis*). | 0.4 |
| | Incomplete thickness of Decker Formation. | 55.0 |

## SECTION 4

# PARTS OF BLOOMSBURG RED BEDS, POXONO ISLAND FORMATION, BOSSARDVILLE LIMESTONE AND DECKER FORMATION

Part of the Bloomsburg Red Beds, Poxono Island Formation, Bossardville Limestone, and part of the Decker Formation in water well drilled at the east plant of the

New Jersey Zinc Company, Palmerton, Pennsylvania, 1,900 feet east of the intersection of Mill Creek and Aquashicola Creek. Modified from log description by John L. Rodda. Beds are overturned to the southeast and younger rocks are encountered with depth. Altitude at top of casing is 422 feet. Total depth is 685 feet. Location of contacts may be approximate. Section measured by J. B. Epstein.

| *Unit* | *Lithologic description* | *Depth (in feet)* |
|---|---|---|
| 5 | Overburden, mixture of fragments of red and pinkish shale, greenish and whitish calcareous shale, limestone, and sandstone. | 0–60 |
| *Bloomsburg Red Beds (part)* | | |
| 4 | Shale, reddish, greenish, and calcareous in part, sandy. Some fibrous aragonite. May include some rocks of the Poxono Island Formation. | 60–200 |
| *Poxono Island Formation* | | |
| 3 | Shale, gray to greenish, calcareous, partly sandy; some dolomite and pyrite. | 200–500 |
| *Bossardville Limestone* | | |
| 2 | Limestone, light- to dark-gray, shaly; microfossils. | 500–620 |
| *Decker Formation (part)* | | |
| 1 | Sandstone, brown, fine-grained, pebbly, ferruginous. | 620–685 |

## SECTION 5

# RIDGELEY, SCHOHARIE-ESOPUS, AND PALMERTON FORMATIONS

Described section of the Ridgeley, Schoharie-Esopus, and Palmerton Formations at West Bowmans. Exposure is at road level on the east side of the Northeast Extension of the Pennsylvania Turnpike north of Lizard Creek. Base of section is at approximately 40°47′40″ N/75°40′18″ W. Section measured by W. D. Sevon.

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| *Palmerton Formation* | | |
| (108.47 feet thick; complete) | | |
| 50 | Sandstone, coarse- to very coarse grained, very light gray (N8), yellowish-gray (5Y8/1) weathered color; numerous irregularly shaped 1- to 2-in.-diameter masses of brownish-black (5YR2/1) material which may be dead petroleum; subangular to subrounded quartz grains; massive; variable cementation by silica becomes weaker upwards; irregular but sharp upper contact. | 2.0 |
| 49 | Sandstone, coarse- to very coarse grained, white; weathers to yellowish gray (5Y8/1); some ¼- to ½-in.-diameter masses of brownish-black (5YR2/1) material which may be dead petroleum; subangular to subrounded quartz grains; some clay matrix; moderate sorting; gradational upper contact. | 3.67 |
| 48 | Sandstone, coarse- to very coarse grained, light-gray (N7); weathers yellowish gray (5Y8/1); subangular to subrounded quartz grains; 10 percent clay matrix; rounded quartz pebbles up to ½ in. in diameter scattered throughout lower 4 ft. and concentrated into a laterally discontinuous 1-in.-thick conglomerate at 2 ft. above the base; moderately indurated; gradational upper contact. | 16.0 |
| 47 | Conglomerate, light-gray (N7) to medium-light-gray (N6); ¼- to ½-in.-diameter rounded quartz pebbles comprise 25 percent of rock; matrix is medium- to very coarse grained quartz sand; scattered ¼-in.-diameter pyrite nodules; quartzitic; 4- to 6-in.-thick zone at base has elongate holes left by weathering of brachiopod shells or shale chips; abruptly gradational upper contact. | 3.0 |
| 46 | Sandstone, very coarse grained quartz grains in matrix of silt to very fine grained sand which comprises 25 to 40 percent of the rock, some iron cement, medium-light-gray (N6) with dark-yellowish-orange (10YR6/6) weathered color; few scattered subrounded quartz pebbles up to ¼ in. in diameter; rare ⅛-in.-diameter pyrite nodules; quartzitic; sharp upper contact. | 11.0 |
| 45 | Sandstone, coarse-grained, medium-light-gray (N6); few scattered very coarse grained grains; rare pebbles up to ¼ in. in diameter; 10 to 20 percent matrix of silt to very fine grained sand; quartzitic; some grayish-orange (10YR7/4) weathered color; some grayish-red (10R4/2) iron stain along joints and bedding planes; gradational upper contact. | 17.5 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 44 | Sandstone, very coarse grained; 10 percent clay matrix; scattered pebbles up to ¼ in. in diameter in upper half becoming more concentrated towards top; subangular to subrounded quartz grains; poorly indurated; gradational upper contact. | 10.0 |
| 43 | Sandstone, very coarse grained, white; subangular to subrounded quartz grains; rare rounded quartz pebbles up to ¼ in. in diameter; 5 to 10 percent clay matrix; some grayish-orange (10YR7/4) weathered color; moderate to good induration; gradational upper contact. | 22.0 |
| 42 | Sandstone, coarse-grained, white; few very coarse grains; 10 percent clay matrix; dusky-red (5R3/4) iron-cemented bands weather dark-reddish brown (10R3/4); stylolites; gradational upper contact. | 13.0 |
| 41 | Sandstone, coarse- to very coarse grained, white; 10 percent clay and silt matrix; some dusky-red (5R3/4) iron cement in matrix weathers moderate-yellowish brown (10YR5/4); moderate induration; gradational upper contact. | 5.75 |
| 40 | Sandstone, very coarse grained, white; 5 percent clay matrix; grayish-orange (10YR7/4) weathered color; some dusky-red (5R3/4) iron cement; moderate induration; sharp upper contact marked by iron-cemented band and knobbly surface. | 0.67 |
| 39 | Sandstone, coarse-grained, white; some very coarse grains; 25 percent clay matrix; subangular to subrounded quartz grains; well indurated; sharp upper contact. | 0.25 |
| 38 | Siltstone, medium- to coarse-grained, very light gray (N8); some very fine grained and rare very coarse grained quartz grains; some grayish-red-purple (5RP4/2) iron stain along fractures; quartzitic; sharp upper contact. | 0.67 |
| 37 | Sandstone, 50 percent very well sorted subangular to rounded coarse-grained quartz grains floating in matrix of silt, white; quartzitic; some dusky-red (5R3/4) iron stain; sharp upper contact. | 0.71 |
| 36 | Siltstone, coarse-grained silt to very fine grained sand, very light gray (N8); few very coarse grained quartz grains; some grayish-orange (10YR7/4) iron stain; quartzitic; some bedding-plane alignment of larger grains in lower 5 in.; sharp upper contact. | 1.83 |
| 35 | Sandstone, coarse- to very coarse grained, white; 5 percent clay matrix; moderate induration; sharp upper contact. | 0.42 |
| | *Schoharie-Esopus Formation*<br>(43.66 feet thick; complete) | |
| 34 | Siltstone, medium-grained, light-gray (N7) with yellowish-gray (5Y8/1) stain, hard, uniform; lower 2½ ft. fossiliferous with *Spirifer* valve molds in discontinuous planes; sharp upper contact. | 4.0 |
| 33 | Shale, no fresh material; weathers to light-gray clay. | 0.04 |
| 32 | Siltstone, fine- to medium-grained, light-gray (N7); moderate-yellowish-brown (10YR5/4) weathered stain; quartzitic; highly fractured; brachiopod molds common throughout; sharp contacts. | 1.33 |
| 31 | Shale, as unit 33. | 0.02 |
| 30 | Siltstone, very fine grained, light-gray (N7), quartzitic; becomes chertlike in upper half; sharp contacts. | 0.58 |
| 29 | Shale, silty, light-olive-gray (5Y6/1), platy, well-indurated; weathers to powdery mass; sharp contacts. | 0.17 |
| 28 | Siltstone, very fine grained, light-gray (N7) with moderate-brown (5YR3/4) iron staining, chertlike; irregular base with up to 2-in. relief; sharp contacts. | 0.58 |
| 27 | Siltstone, very fine grained, light-gray (N7), chertlike, very hard, brittle, massive; sharp contacts. | 2.17 |
| 26 | Shale, as unit 29. | 0.08 |
| 25 | Siltstone, very fine grained, light-gray (N7), hard, massive; wavy internal structure in upper half, chertlike and structureless in lower half; sharp contacts. | 0.75 |
| 24 | Shale, as unit 29. | 0.08 |
| 23 | Siltstone, chertlike, light-gray (N7), structureless; sharp contacts. | 0.5 |
| 22 | Siltstone, fine-grained, medium-light-gray (N6); weathers pale-yellowish brown (10YR6/2); hard; brittle; chertlike; numerous fractures normal to bedding, some filled with quartz; some scattered brachiopod molds; sharp contacts. | 2.0 |
| 21 | Shale, as unit 29. | 0.08 |
| 20 | Siltstone, fine-grained, medium-light-gray (N6); dark lines of medium-dark-gray (N4) color may be organic matter concentrations; sharp contacts. | 0.67 |
| 19 | Siltstone, fine-grained, medium-light-gray (N6); dark organic(?)-rich lines of medium-dark gray (N4); line pattern is parallel to bedding; yellowish-gray (5Y8/1) weathered color along fractures; brownish-black (5YR3/1) iron stain in places; hard; uniform; sharp contacts. | 2.42 |
| 18 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2); few very coarse grained quartz grains and some mica flakes; sharp upper contact; gradational basal contact. | 0.83 |
| 17 | Siltstone, medium- to coarse-grained, medium-dark-gray (N4) to medium-gray (N5); organic-rich concentrations in dark-gray (N3) lines generally parallel to bedding; some structures resembling overturned crossbeds; some massive and structureless intervals; sharp basal contact. | 3.33 |
| 16 | Shale, as unit 29. | 0.04 |
| 15 | Siltstone, similar to unit 17, but with more overturned crossbed structures; burrow structures with light-olive-gray (5Y6/1) color; sharp parting contacts. | 5.33 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 14 | Siltstone, similar to unit 15, with well-developed overturned crossbed structures in ¼- to ½-in.-thick laminae; crossbeds have tangential bases and truncated tops; sharp parting contacts. | 2.0 |
| 13 | Siltstone, similar to unit 14; crossbeds show well-developed overturning in opposite directions in succeeding laminae; sharp parting contacts. | 2.83 |
| 12 | Siltstone, a sequence of alternating massive and shaly siltstone units; typical massive unit is medium to coarse grained, medium gray (N5) to medium-dark gray (N4) with fine dark-gray (N3) lines delineating overturned crossbed structure; opposite directions of overturning on succeeding laminae; laminae ¼ to ½ in. thick; nearly complete scour of some laminae, 4½-in. average thickness; typical shaly unit is medium grained, olive gray (5Y4/1), mottled with dark gray (N3); massive platy disintegration is more rapid than massive interbed, 2-in. average thickness; both units become thinner and more shaly towards base. | 10.0 |
| 11 | Shale, silty, medium-gray (N5); weathers to near dusky yellow (5Y6/4) and yellowish gray (5Y8/1) but surface of crop appears white; weakly indurated; disintegration to platy mass, then to clayey mass; gradational upper contact; sharp basal contact. | 3.0 |
| *Ridgeley Formation*<br>(17.66 feet thick; complete?) | | |
| 10 | Conglomerate, 50 percent 2-mm- to ½-in.-diameter white quartz pebbles, fine- to medium-grained sand matrix; iron cement; grayish-red-purple (5RP4/2) to grayish-red (5R4/2); hard; becomes dominantly sandstone in uppermost 1 in.; iron concentration decreases downward; gradational lower contact. | 0.42 |
| 9 | Conglomerate, 25 percent 2-mm- to ⅛-in.-diameter white quartz pebbles, fine- to medium-grained quartz sand matrix, 5 percent clay matrix; brownish-black (5YR2/1) iron stain; rare pebbles up to ½ in. in diameter; planes of aligned brachiopod valve molds at 1½ and 3½ ft. above base, valves oriented convexly upward; slight upward decrease in pebble size and quantity; basal few in. may have up to 75 percent pebbles; gradational lower contact. | 4.0 |
| 8 | Conglomerate, 50 to 75 percent ⅛- to ¼-in.-diameter quartz pebbles, medium- to coarse-grained sand matrix, some clay, white, weakly indurated; gradational lower contact. | 1.17 |
| 7 | Sandstone, fine- to medium-grained, white with grayish-orange weathered tint, well-sorted, structureless; moderate induration; gradational contacts. | 1.08 |
| 6 | Sandstone, 25 to 40 percent very coarse grained quartz grains floating in fine-grained sand matrix, white with grayish-orange (10YR8/4) weathered tint; gradational contacts. | 1.33 |
| 5 | Sandstone, as unit 7. | 0.33 |
| 4 | Sandstone, as unit 6, with planes of brachiopod valve molds oriented convexly upward at base and 1 ft. 2 in. above base. | 2.0 |
| 3 | Sandstone, 50 percent very coarse grained quartz grains, medium-grained sand matrix, white with grayish-orange (10YR8/4) weathered tint; scattered brachiopod valve molds oriented convexly upward; gradational contacts. | 3.25 |
| 2 | Sandstone, fine-grained, white; weathers grayish-orange (10YR8/4); well sorted; structureless; moderately indurated. | 1.25 |
| 1 | Sandstone, coarse- to very coarse grained with ⅛- to ¼-in.-diameter quartz pebbles at top, some clay, white with grayish-orange (10YR8/4-6/4) weathered tint; weak to moderate induration. Base of section. | 2.83 |
| | Total | 168.96 |

## SECTION 6

## BUTTERMILK FALLS LIMESTONE

Described section of the Buttermilk Falls Limestone at West Bowmans. Exposure is along first terrace on east side of Northeast Extension of the Pennsylvania Turnpike about 800 feet south of Pa. Route 895. Rock material is highly weathered and it is doubtful whether any of the lithologies described represent fresh rock material. Base of the section is approximately at 40°47′43″ N/75°40′19″ W. Section measured by W. D. Sevon.

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| *Marcellus Formation*<br>(incomplete) | | |
| 105 | Shale, clay, black, massive; disintegrates into fissile plates. | several hundred |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 104 | Tioga bentonite, medium-dark-gray (N4); medium- to coarse-grained mica flakes occur but are not abundant; numerous pyrite nodules up to 1 mm in diameter; silvery appearance imparted by mica; sharp contacts. | 0.06 |
| 103 | Clay ironstone, blackish-red (5R2/2) to brownish, irregularly bedded; sharp contacts. | 0.06 |
| 102 | Tioga bentonite, medium-dark-gray (N4) clay with medium-grained or finer mica flakes; numerous pyrite nodules up to 1 mm in diameter; silvery appearance imparted by mica; sharp contacts. | 0.06 |
| 101 | Clay ironstone, blackish-red (5R2/2) to brownish, irregularly bedded; sharp contacts. | 0.17 |
| 100 | Tioga bentonite, medium-dark-gray (N4); medium- to coarse-grained mica flakes abundant in clay; numerous pyrite nodules up to 1 mm in diameter; silvery appearance imparted by mica; sharp contacts. | 0.17 |
| 99 | Clay ironstone, blackish-red (5R2/2) to hrownish, irregularly bedded; gradational lower contact. | 0.06 |
| 98 | Shale, clay, black, weak; gradational contacts. | 0.08 |
| 97 | Shale, clay, moderate-brown (5YR3/4), weak; gradational contacts. | 0.04 |
| 96 | Shale, clay, black, weak; gradational contacts. | 0.17 |
| 95 | Shale, silty, black, fossiliferous, massive, hard; gradational upper contact; sharp lower contact. | 0.5 |
| *Buttermilk Falls Limestone* | | |
| (40.26 feet thick; complete) | | |
| 94 | Siltstone, fine- to medium-grained, light-gray (N7) to very light gray (N8), hard, sparsely fossiliferous, massive; sharp lower contact. | 1.0 |
| 93 | Shale, clay, black; thin parting with sharp contacts. | 0.01 |
| 92 | Siltstone, as unit 94; sharp contacts. | 0.23 |
| 91 | Shale, silty clay, light-gray (N7); parting with sharp contacts. | 0.01 |
| 90 | Siltstone, as unit 94; sharp contacts. | 0.23 |
| 89 | Shale, silty clay, light-gray (N7); sharp contacts, parting. | 0.01 |
| 88 | Siltstone, as unit 94; sharp contacts. | 0.75 |
| 87 | Clay, light-brown (5YR5/6), laminated; abrupt upper gradational contact; sharp lower contact. | 0.08 |
| 86 | Siltstone, fine-to medium-grained, light-gray (N7) to very light gray (N8), hard, sparsely fossiliferous, massive, considerably iron stained in basal 2 in.; sharp contacts. | 1.42 |
| 85 | Siltstone, fine-grained, near moderate-yellow (5Y7/6), very leached, very fossiliferous; sharp contacts. | 0.33 |
| 84 | Siltstone, fine-grained, light-gray (N7); iron staining parallel to laminae is grayish orange (10YR7/4); sparsely fossiliferous; massive blocks up to 6 in. thick; gradational lower contact. | 2.33 |
| 83 | Siltstone, fine-grained, very light gray (N8), iron-stained to light brown (5YR5/6); lateral variation from sparsely to abundantly fossiliferous; highly leached; gradational lower contact. | 0.83 |
| 82 | Clay, silty, moderate-brown (5YR5/6), soft, flaky; sharp lower contact. | 0.08 |
| 81 | Siltstone, fine-grained, very light gray (N8), with light-brown (5YR5/6) iron stain, massive, blocky; abundant molds of brachiopod valves and some other unidentified fossils; some siliceous shell material; sharp contacts. | 0.67 |
| 80 | Chert, black, highly fractured; sharp contacts. | 0.19 |
| 79 | Siltstone, as unit 81; sharp contacts. | 0.33 |
| 78 | Chert, black, highly fractured; sharp contacts. | 0.10 |
| 77 | Siltstone, fine-grained in lower half to very fine grained in upper half, very light gray (N8); light-brown (5YR5/6) iron stain and some tendency for overall pale-yellowish-brown (10YR6/2) weathered color in upper half; gradational lower contact. | 3.08 |
| 76 | Siltstone, fine-grained, light-olive-gray (5Y5/2), hard, highly leached and porous; sharp lower contact. | 1.42 |
| 75 | Silt, ocher (golden-orange; color not on chart), very fine grained to fine-grained; disintegrates into very soft mass; may contain some fossil material and some leached chert; gradational lower contact. | 0.25 |
| 74 | Siltstone, fine-grained, light-olive-gray (5Y5/2), hard, highly leached and porous; sharp lower contact. | 0.17 |
| 73 | Shale, clay, black; platy pieces on breakup; weathers to various light-gray shades; some laminae parallel to bedding; gradational lower contact. | 0.75 |
| 72 | Siltstone, fine-grained, dark-yellowish-orange (10YR6/6) to light-brown (5YR5/6), hard, porous, probably highly leached limestone; gradational lower contact—may be same as underlying unit. | 0.58 |
| 71 | Siltstone, fine-grained, in part nearly a clay, dark-yellowish-orange (10YR6/6) to pale-red (5R6/2), probably deeply leached limestone, massive, structureless; some harder layers suggest gray original color; sharp lower contact. | 4.33 |
| 70 | Siltstone, medium-grained, dark-yellowish-orange (10YR6/6), massive, fairly hard, probably leached limestone; scattered fossils; sharp lower contact. | 0.5 |
| 69 | Siltstone, fine-grained, pale-red (10R7/2), hard; some mica flakes; platy disintegration; fossils scattered sparsely throughout; gradational lower contact. | 0.37 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 68 | Shale, clay, dark-gray (N3); weathers to mottled lighter shades of gray; some iron concentration in seams along parting; abruptly gradational lower contact. | 0.25 |
| 67 | Clay ironstone, grayish-red (5R4/2); some fissility on breakup; sharp lower contact. | 0.17 |
| 66 | Siltstone, very fine grained, near dark-yellowish-orange (10YR6/6); some moderate-reddish-brown (10R4/6) iron stain in center and upper 2 in.; massive; blocky; probably leached limestone; gradational lower contact. | 2.33 |
| 65 | Clay, between light-brown (5YR5/6) and dark-yellowish-orange (10YR6/6); abruptly gradational lower contact. | 0.21 |
| 64 | Silt, very fine to fine-grained, moderate-reddish-brown (10R4/6) at base and top 1 in. is gradational into central golden-orange color near dark-yellowish orange (10YR6/6); fossil molds scattered throughout; sharp lower contact. | 0.62 |
| 63 | Clay, near pale-yellowish-brown (10YR6/2); weathers to grayish orange (10YR9/4) in thin plates; fresher material is massive and seems to have very fine grained mica flakes; has soapy feel; has few scattered fossils and mottled weathered color; gradational lower contact. | 0.62 |
| 62 | Clay, highly micaceous with fine- to medium-grained mica flakes; dark-yellowish orange (10YR6/6) weathers to pale-yellowish orange (10YR9/6); sharp lower contact. | 0.25 |
| 61 | Clay, dark-yellowish-orange (10YR6/6); thickens and thins laterally; highly micaceous with medium-grained mica flakes; weathers to pale-yellowish orange (10YR9/6); contains some black iron concentration in planes parallel to bedding; sharp lower contact. | 0.12 |
| 60 | Clay ironstone, black with metallic sheen; hard material has abundant pores and irregularities causing it to break down readily; sharp lower contact. | 0.08 |
| 59 | Siltstone, fine-grained, grayish-red (5R4/2), hard, blocky; sharp lower contact. | 0.12 |
| 58 | Chert, black; leached margins; sharp contacts. | 0.12 |
| 57 | Silt, very fine grained to fine-grained; color varies from moderate yellowish brown (10YR5/4) to near white; some mottling of grayish orange (10YR7/4) and moderate brown (5YR4/4) with suggestion that fresher material is light gray (N7) or darker; hard; porous; iron stain near moderate-reddish brown (10R4/6); fossil molds in upper part; sharp contacts. | 0.62 |
| 56 | Clay, black; may be iron rich; sharp contacts. | 0.02 |
| 55 | Silt, fine-grained to very fine grained, near moderate-brown (5YR4/4) with central ¼ in. leached to near very pale orange (10YR8/2); sharp contacts. | 0.17 |
| 54 | Chert, black; may be laterally discontinuous; sharp contacts. | 0.12 |
| 53 | Clay, near moderate-yellowish-brown (10YR5/4); gradational lower contact. | 0.21 |
| 52 | Clay, grayish-red (5R4/2); parallel laminae; abrupt gradational lower contact. | 0.04 |
| 51 | Clay, near yellowish-orange (10YR5/5); abundant fossil molds of brachiopods, corals, crinoid columnals; rare siliceous shells; molds are stained grayish black (N2) by iron; gradational lower contact. | 0.75 |
| 50 | Clay, silty, near light-brown (5YR5/6) at base, becomes slightly lighter upwards; parallel laminae; gradational lower contact. | 0.17 |
| 49 | Silt, very fine to fine-grained; base and top are moderate-yellowish brown (10YR5/4); center 2 in. is near grayish-yellow (5Y8/4) with grayish-black (N2) spots up to ¼ in. in diameter; sharp lower contact. | 0.42 |
| 48 | Clay, grayish-red (5R4/2); sharp contacts. | 0.02 |
| 47 | Limestone, completely leached leaving moderate-brown (5YR4/4) pithy material with 3 black chert layers; sharp contacts. | 0.33 |
| 46 | Shale, clay, medium-dark-gray (N4); weathers to grayish orange (10YR8/4); massive; blocky; disintegrates into ¼ to ⅛ in. pieces; fossil material scattered throughout; gradational lower contact. | 0.46 |
| 45 | Clay, near moderate-brown (5YR4/4); some fossil material; distinct parallel laminae; gradational lower contact. | 0.5 |
| 44 | Clay, between grayish-orange (10YR7/4) and moderate-yellowish-brown (10YR5/4) with black iron stain on some laminae surfaces; fossil material parallel to laminae; slightly indurated in upper half; gradational lower contact. | 0.92 |
| 43 | Clay, grades upward from grayish orange (10YR7/4) at base to dark-yellowish orange (10YR6/6); parallel laminae; gradational lower contact. | 0.37 |
| 42 | Clay, moderate-brown (5YR3/4); parallel laminae; gradational lower contact. | 0.12 |
| 41 | Clay, near pale-yellowish-brown (10YR6/2); fossil material parallel to laminae; sharp lower contact. | 0.31 |
| 40 | Clay, light-brown (5YR5/6); sharp contacts. | 0.02 |
| 39 | Clay, color varies from dusky yellow (5Y6/4) to light brown (5YR6/4) and very pale orange (10YR8/2); sharp lower contact. | 0.46 |
| 38 | Clay, dark-gray (N3) to grayish-black (N2); weathers to various shades of olive with black iron coatings on some surfaces; fossil material; parallel laminae; gradational lower contact. | 0.08 |
| 37 | Clay, various shades of yellowish-brown and olive; abundant fossil material which is mainly broken debris; parallel laminae; sharp lower contact. | 0.58 |
| 36 | Clay, dark-gray (N3) to grayish-black (N2); weathers to various shades of olive; some black iron stain on parallel-laminae surfaces; gradational lower contact. | 0.17 |
| 35 | Clay, moderate-brown (5YR3/4); suggestion of parallel laminae; sharp lower contact. | 0.33 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 34 | Limestone, medium-dark-gray (N4), massive, hard, structureless; smooth fracture; margins are leached and show brownish color as well as presence of brachiopods, corals, and crinoid columnals; sharp lower contact. | 0.25 |
| 33 | Shale, calcareous, medium-dark-gray (N4), blocky; contains brachiopods, crinoid columnals, and trails (?); gradational lower contact. | 0.33 |
| 32 | Shale, calcareous, medium-dark-gray (N4); scattered brachiopod valve molds; fissile at base becoming more blocky upwards; sharp lower contact. | 0.42 |
| 31 | Shale, dark-gray (N3) in part but mostly medium-dark gray (N4) with definite bluish color which is nearest to grayish blue (5BP4/2); breaks up into hackly pieces at first and rapidly disintegrates into a clay mass; uniform throughout; massive; structureless; sharp lower contact. | 0.75 |
|  | *Hazard paint ore* |  |
| 30 | Clay ironstone, grayish-red (5R4/2), hard, resistant unit; some fissility evident during breakdown; sparsely scattered ⅛-in. or less nodules of iron (?); gradational lower contact. | 0.46 |
| 29 | Shale, black, massive, weak; breaks up into plates and weathers to light-gray shades; gradational lower contact. | 0.54 |
| 28 | Clay ironstone, as unit 30; gradational lower contact. | 0.58 |
|  | *Lower shale member* |  |
| 27 | Shale, black, massive, blocky, hard; weathers to lighter shades of gray initially, then to olive shades; some platy pieces are moderate-yellowish brown (10YR5/4); gradational lower contact. | 0.19 |
| 26 | Shale, as unit 31; gradational lower contact. | 0.10 |
| 25 | Shale, as unit 31 but with some moderate-yellowish-brown (10YR5/4) weathered color; gradational lower contact. | 0.12 |
| 24 | Shale, as unit 31; gradational lower contact. | 0.17 |
| 23 | Shale, grayish-black (N2); weathers to near dusky-yellow (5Y6/4) and has considerable dark-yellowish-brown (10YR4/2) iron-stained material; breaks up into hackly pieces; some suggestion of parallel laminae; sharp lower contact. | 0.67 |
| 22 | Claystone, near olive-gray (5Y4/1); weathers to near dusky-yellow (5Y6/4); blocky nature; suggestion of parallel laminae; gradational lower contact. | 0.21 |
| 21 | Shale, as unit 31; abruptly gradational lower contact. | 1.42 |
| 20 | Shale, between moderate-brown (5YR4/4) and moderate-yellowish-brown (10YR5/4) with dusky-red (5R3/4) spots; slight fissility; gradational lower contact. | 0.33 |
| 19 | Claystone, dark-yellowish-brown (10YR4/2); weathers to moderate-yellowish brown (10YR5/4); hard; sharply gradational lower contact. | 0.08 |
| 18 | Clay, between moderate-red (5R4/6) and dusky-red (5R3/4) with irregular mottles of medium-light gray (N6); sharp lower contact. | 0.10 |
| 17 | Clay, near dusky-brown (5YR4/6), iron-cemented, hard; sharp lower contact. | 0.02 |
| 16 | Clay, dark-yellowish-orange (10YR6/6) and light-gray (N7) mixed; suggestion of parallel laminae; sharp lower contact. | 0.04 |
| 15 | Clay, as unit 17; sharp lower contact. | 0.02 |
| 14 | Clay, as unit 16; sharp lower contact. | 0.12 |
| 13 | Clay, between moderate-red (5R4/6) and moderate-reddish-brown (10R4/6); weathers to lighter shades of reddish orange; sharp lower contact. | 0.08 |
| 12 | Shale, moderate-brown (5YR4/4) to grayish-red (5R4/2), iron-cemented, hard; suggestion of parallel laminae; gradational lower contact. | 0.17 |
| 11 | Shale, originally near medium-gray (N5), now weathered to dark-yellowish orange (10YR6/6); gradational lower contact. | 0.5 |
| 10 | Clay, between grayish-orange (10YR7/4) and dark-yellowish-orange (10YR6/6) with irregular thin layers of medium-gray (N5); 1 to 5 percent rounded coarse-grained quartz grains scattered throughout; probably a more weathered part of unit 11; abrupt lower contact. | 0.21 |
| 9 | Clay, dusky-red (5R3/4); weathers from light brown (5YR5/6) to dark-yellowish orange (10YR6/6); contains 25 to 40 percent rounded coarse-grained quartz grains floating in clay; gradational lower contact. | 0.17 |
| 8 | Clay, dusky-red (5R3/4); about 50 percent coarse-grained quartz grains floating in clay; very soft; gradational lower contact. | 0.08 |
| *Palmerton Formation* |  |  |
| (3.39 feet thick; incomplete) |  |  |
| 7 | Sandstone, coarse-grained to very coarse grained, some pebbles to ¼ in. in diameter, iron-stained to dark-yellowish orange (10YR6/6); pebbles rounded; rare spots of black material (dead petroleum?); abruptly gradational lower contact. | 0.83 |
| 6 | Sandstone, coarse-grained to very coarse grained, grayish-red (5R4/2), iron-cemented, laterally discontinuous; abruptly gradational lower contact. | 0.02 |
| 5 | Sandstone, coarse-grained to very coarse grained, dark-yellowish-orange (10YR6/6); scattered pebbles of rounded quartz up to ¼ in. in diameter, gradational lower contact. | 0.67 |
| 4 | Sandstone, as unit 6; gradational lower contact. | 0.04 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 3 | Sandstone, coarse-grained to very coarse grained; light color tinted yellowish by iron stain; scattered spots of black material (dead petroleum?) are ⅛ to ¼ in. in diameter at base and increase to 3 to 4 in. in diameter at top where they form an almost solid black mass; weakly indurated; forms recess; gradational lower contact. | 0.75 |
| 2 | Sandstone, coarse-grained to very coarse grained; few scattered ⅛- to ¼-in.-diameter masses of black material (dead petroleum?); very poorly indurated zone weathers to form recess; light color is stained yellowish by iron; gradational lower contact. | 1.08 |
| 1 | Sandstone, coarse-grained to very coarse grained, white, weakly indurated, some yellowish iron stain; top of indurated zone of the Palmerton. Base of described section. | |
| | Total | 45.02 |

# SECTION 7

## MAHANTANGO FORMATION

Described section through the Mahantango Formation north of Weissport. Section occurs along the east side of the old Lehigh Canal. The section ends at the south end of a gully containing sanitary landfill and continues south to the center of the Lehighton anticline. Beds are nearly vertical throughout. Base of section is approximately at 40° 50′ 18″ N/70°42′12″ W. Section measured by W. D. Sevon.

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| *Mahantango Formation* | | |
| (1,552–1,952 feet thick; complete) | | |
| | *Tully fossil zone*<br>(8 feet thick; complete?) | |
| 33 | Shale, dark-gray (N3), calcareous, fossiliferous, containing brachiopod valves and crinoid columnals; no cleavage; upper contact lost in cover; lower contact gradational. *Base of Tully fossil zone.* | 8.0 |
| 32 | Shale, dark-gray (N3); prominent cleavage; occasional crinoid columnals; some bedding traces; gradational lower contact. | 3.0 |
| 31 | Shale, dark-gray (N3) to grayish-black (N2); prominent cleavage; hard; spherical nodules up to 1½ in. in diameter in upper 10 ft. are aligned along bedding. | 40.0 |
| 30 | Shale, etched outcrop shows parallel laminations and irregular wavy laminations occurring as thin (1/16- to ⅛-in.-thick fine-grained siltstone) beds; intense minute fracturing parallel to cleavage; some thin beds up to ½ in. thick which are more resistant to weathering are numerous and are 2 to 3 in. apart. | 12.0 |
| 29 | Shale, dark-gray (N3) to grayish-black (N2). | 130.0 |
| | *Nis Hollow siltstone*<br>(14 feet, 2 inches thick; complete) | |
| 28 | Siltstone, coarse-grained to very coarse grained alternating with medium-grained siltstone. Detailed sequence as follows:<br>0′ 7″ Siltstone, very coarse grained, poorly defined bed; some animal burrow structure.<br>4′ 0″ Siltstone, medium-grained; may have some intermixed coarser material.<br>0′ 8″ Siltstone, very coarse grained, well-defined; some parallel laminae at top; rusty weathered color; blocky sharp contacts.<br>0′ 3″ Siltstone, medium-grained.<br>0′ 8″ Siltstone, coarse to very coarse grained, well-defined band; upper contact sharp; gradational lower contact.<br>2′ 6″ Siltstone, medium-grained; sharp lower contact.<br>0′ 5″ Siltstone, very coarse grained; gradational lower contact.<br>0′ 5″ Siltstone, medium-grained.<br>0′ 6″ Siltstone, very coarse grained; bed not well defined.<br>0′ 5″ Siltstone, medium-grained; sharp lower contact.<br>1′ 3″ Siltstone, very coarse grained, massive; blocky thickness laterally variable from 10 in. to 1 ft. 3 in.<br>2′ 4″ Siltstone, medium-grained.<br>0′ 2″ Siltstone, very coarse grained, poorly defined. | 14.2 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| | *Base of Nis Hollow siltstone* | |
| 27 | Shale, dark-gray (N3); prominent cleavage. | 30.0 |
| 26 | Shale, dark-gray (N3), hard, well-defined band. | 0.12 |
| 25 | Shale, dark-gray (N3); prominent cleavage. | 0.75 |
| 24 | Shale, dark-gray (N3), hard, well-defined band. | 0.08 |
| 23 | Shale, dark-gray (N3) to grayish-black (N2); prominent cleavage; disintegrates to fine pencil-like chips or to thin flakes. | 260.0 |
| 22 | Covered interval, broad gully. | 130.0 |
| | *Centerfield fossil zone*<br>(40 feet thick; complete?) | |
| 21 | Shale, dark-gray (N3), calcareous, fossiliferous; has brachiopod valves, crinoid columnals, bryozoans, horn corals; upper contact probably not true upper limit of zone. | 5.0 |
| 20 | Shale, dark-gray (N3), calcareous, nonfossiliferous. | 5.0 |
| 19 | Shale, as unit 21. | 30.0 |
| | *Base of Centerfield fossil zone* | |
| 18 | Covered interval. | 50.0 |
| 17 | Shale, dark-gray (N3); prominent cleavage. | 70.0 |
| 16 | Shale, dark-gray (N3); prominent cleavage; hard. | 80.0 |
| 15 | Shale, dark-gray (N3); prominent cleavage. | 100.0 |
| 14 | Covered interval, recessed gully. | 120.0 |
| 13 | Shale, dark-gray (N3); prominent cleavage. | 60.0 |
| 12 | Shale, dark-gray (N3); prominent cleavage; hard; conspicuous outcrop just out into canal. | 30.0 |
| 11 | Shale, dark-gray (N3); 2 bands of concretions aligned with bedding. | 1.0 |
| 10 | Shale, dark-gray (N3); prominent cleavage. | 50.0 |
| 9 | Covered interval, gully. | 120.0 |
| 8 | Covered interval, rhododendron-covered slope; float shows no change from unit 10. | 180.0 |
| | *Little Gap fossil zone*<br>(20 feet thick; complete) | |
| 7 | Shale, medium-dark-gray (N4) to dark-gray (N3), calcareous; crinoid columnals, brachiopod valves, trilobites, bedding obvious. | 20.0 |
| | *Base of Little Gap fossil zone* | |
| 6 | Shale, dark-gray (N3); contains several bands of discoidal concretions up to 1 in. thick and 3 in. in diameter spaced at 6-in. to 1-in. intervals. | 3.0 |
| *Mahantango-Marcellus Formations*<br>(400 feet thick; transition) | | |
| 5 | Shale, dark-gray (N3) to grayish-black (N2); prominent cleavage; partial cover and partial outcrop. | 400.0 |
| *Marcellus Formation*<br>(800 feet thick; incomplete) | | |
| 4 | Shale, as unit 5 (?); gully recess with partial outcrop. | 190.0 |
| 3 | Shale, grayish-black (N2); prominent cleavage; cross small stream 30 ft. below top. | 200.0 |
| 2 | Shale, clayey, grayish-black (N2) to black (N1); some silt in upper part; base of unit is center of canal crossover. | 290.0 |
| 1 | Shale, clayey, black (N1); abundant iron staining; extensively crushed; measurement stopped at point considered to be axis of anticline. | 120.0 |

## SECTION 8

## TRIMMERS ROCK FORMATION

Reference section of the Trimmers Rock Formation, located along the east bank of the Lehigh River on Pa. Route 248 between Bowmanstown and Parryville (Figure 93). Base of section is approximately at 75°40′07″N/40°48′16″W. Section measured by J. D. Glaeser and W. D. Sevon.

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 95C | Siltstone, fine- to medium-grained, medium-gray (N5). Plant material on bed surfaces. Loaded by overlying Towamensing sand. Undulatory top with 6-in. relief. Dirty siltstone fines upward and becomes more fissile. | 7.8 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 95B,A | Siltstone, coarse- to fine-grained, three graded beds, medium-gray (N5) to medium-light-gray (N6). Top 1 in. sharp and wavy, bioturbated. Rest of unit has yellow and orange coating of relic carbonaceous matter. | 1.0 |
| 94C | Siltstone, coarse- and fine-grained. Top transitional and mixed. Interbeds lack ripples. Three to 4 in. of coarse-grained siltstone. | 3.5 |
| 94B | Siltstone, coarse- to medium-grained, medium-gray (N5). Structureless. | 3.4 |
| 94A | Siltstone, coarse- and fine-grained, medium-gray (N5), interlaminated. Burrow mottling in thicker fine-grained siltstone and braided laterally. Abundant massive wispy interbeds and interlaminations. | 3.5 |
| 93B | Siltstone, coarse- to fine-grained, dark-gray (N3) to medium-dark-gray (N4). Massive. Top sharp and planar. Medium- to coarse- grained siltstone interbeds ½ in. thick. | 3.91 |
| 93A | Siltstone, coarse- to fine-grained, medium-gray (N5) to dark-gray (N3). Two graded beds. Coarse-grained siltstone load casted with parallel laminations and burrows. | 3.0 |
| 92 | Siltstone, fine- and medium-grained, medium-dark-gray (N4) to medium-gray (N5). Massive with 2- to 3½-in. coarse-grained siltstone layers in upper half. Some burrowing. Top sharp and loaded by unit 93. | 4.16 |
| 91B | Siltstone, coarse- to medium-grained, medium-dark-gray (N4). Interbedded, braided, lenticular, and graded beds less than 1 in. thick. Some burrowing. Top has sharp parting plane. | 18.3 |
| 91A | Siltstone, medium- to coarse-grained, medium-dark-gray (N4) to medium-gray (N5). Few coarse-grained siltstone interbeds. Some graded. Load casting in lower 2 ft. with long axes parallel to bedding. Top marked by increasing coarse-grained siltstone; top sharp and burrow mottled and has abundant mica. | 19.0 |
| 90 | Siltstone, coarse- to fine-grained, dark-gray (N3) to medium-gray (N5). Seven large graded beds. Massive. Dominantly coarse-grained siltstone with occasional shale-chip horizon at base of graded units. Upper zones of each bed rippled with lozenges of coarse- to medium-grained siltstone. Each base knife sharp. Few load casts in coarse-grained siltstone. | 22.0 |
| 89C | Siltstone, medium- to coarse-grained, medium-dark-gray (N4) to medium-gray (N5). Two massive units. Top knife sharp. | 4.42 |
| 89B | Siltstone, coarse- and medium-grained, braided and lenticular. Unit is upper part of graded bed. Burrowed. Sharp rippled top and bottom. | 0.91 |
| 89A | Siltstone, medium- to coarse-grained, medium-dark-gray (N4) to medium-gray (N5). Basal load casts with up to 3 ft. of relief. Massive casts 6 in. to 6 ft. long and subparallel to beds. | 6.25 |
| 88 | Siltstone, fine- to medium-grained, medium-dark-gray (N4). Homogeneous with lozenge-shaped medium-grained siltstone. Abundant burrowing and other organic activity. Top gradational, loaded. | 12.0 |
| 87B | Siltstone, fine- to coarse-grained, medium-dark-gray (N4) to medium-gray (N5). Load casts: 8 ft. in long dimension and subparallel to bedding. Some parallel laminations in fine- and coarse-grained siltstone. Fine-grained siltstone present through entire thickness. Top braided and is top of load cast. | 7.0 |
| 87A | Siltstone, fine- to medium-grained, medium-dark-gray (N4). Structureless. Massive. Grades in upper 1 ft. into 87B. | 3.5 |
| 86 | Siltstone, fine- to coarse-grained, medium-dark-gray (N4) to medium-gray (N5). Massive. Four graded beds interlaminated and interlayered in upper half. Some wavy contacts. Some burrow mottling in top. | 7.0 |
| 85 | Siltstone, coarse-grained, medium-dark-gray (N4) to medium-gray (N5). Massive. Structureless appearance but may be parallel laminated. Top sharp and planar. | 2.58 |
| 84C | Siltstone, coarse- to fine-grained, medium-dark-gray (N4). Massive. Three graded beds in lower half. Upper half intermixed, interlayered, and braided with coarse-grained siltstone in dominantly fine to medium grained siltstone. | 6.0 |
| 84B | Siltstone, coarse- to medium-grained. Base has brachiopods and shale chips. Massive and braided with fine-grained siltstone. Crinoid columnals in middle and top. Mottled with sand-sized micas. | 7.3 |
| 84A | Siltstone, fine- to coarse-grained, medium-dark-gray (N4) to medium-gray (N5). Seven massive coarse-grained siltstone beds 2 to 4 in. thick. Base of unit has micro-crossbeds. Interbeds with fine- to medium-grained siltstone with stringers, lenses, and burrows of medium- to coarse- grained siltstone. Top rippled. | 6.0 |
| 83 | Siltstone, medium- to coarse-grained, dark-gray (N3). Massive. Intermixed and interlaminated coarse-grained siltstone. Some beds graded. All bioturbated. Scattered crinoid columnals near base. Top sharp and scoured. | 10.16 |
| 82 | Siltstone, fine- to coarse-grained, dark-gray (N3) to medium-dark-gray (N4). Massive. Lower half dominantly parallel laminated with paper-thin fine- to medium-grained siltstone. Upper half mixed fine- and coarse-grained siltstone with increasing clay content. Top 4 in. burrow mottled and has plant imprints. Top sharp and wavy. | 5.08 |
| 81 | Siltstone, fine- to coarse-grained, medium-dark-gray (N4) to medium-gray (N5). Several graded beds. Top sharp and wavy. | 4.58 |
| 80 | Siltstone, fine- to coarse-grained, medium-dark-gray (N4) to dark-gray (N3). Massive. Fine- to medium-grained siltstone interbeds. Most beds planar with parallel laminations. Some lenticular coarse-grained siltstone reworked by organisms. Top sharp and wavy. | 4.0 |

| Unit | Lithologic description | Thickness (in feet) |
|---|---|---|
| 79 | Siltstone, medium- to coarse-grained, dark-gray (N3) to medium-dark-gray (N4). Massive. Lower 2 ft. has several graded beds. Unit above is structureless. Many rippled contacts. Upper half is interbedded medium- and coarse-grained siltstone. Top is parting plane. | 12.25 |
| 78 | Siltstone, medium- to coarse-grained, medium-dark-gray (N4). Massive. No internal structure. Upper 2 in. fine-grained siltstone, burrow-mottled. | 2.25 |
| 77 | Siltstone, coarse-grained. dark-gray (N3) to medium-dark-gray (N4). Massive. Streaks and wisps of fine- to medium-grained siltstone. Much bioturbation. Some brachiopods. Top sharp and wavy. | 16.75 |
| 76 | Siltstone, medium- to fine-grained, with some coarse-grained, dark-gray (N3) to medium-gray (N5). Massive. Interbedded and interlaminated. Beds wavy, discontinuous, and lenticular. Burrow mottling and organic reworking. Medium-grained siltstone dominant. Base has shell and shale fragments from reworked underlying bed. Some coarse-grained siltstone with parallel laminations and graded bedding. Top rippled. Plants and shells in upper 4½ ft. | 12.0 |
| 75E | Siltstone, coarse-grained, medium-gray (N5). Massive. Parallel laminated. Shells at base. Top sharp and rippled. | 0.5 |
| 75D | Siltstone, medium- to fine-grained, dark-gray (N3) to medium-dark-gray (N4). Graded. | 1.2 |
| 75C | Siltstone, coarse-grained, medium-gray (N5). Massive. Parallel laminated. Base is load casted. | 0.58 |
| 75B | Siltstone, medium- to fine-grained, dark-gray (N3) to medium-dark-gray (N4). Graded. | 1.2 |
| 75A | Siltstone, coarse-grained, medium-gray (N5). Brachiopod shells at base. Unit massive and structureless. | 0.67 |
| 74 | Siltstone, medium- to fine-grained, dark-gray (N3). Massive. Many graded beds. Some coarse-grained siltstone, parallel-laminated, with wavy bases and tops. Top 3 ft. burrow mottled with brachiopod shells and bryozoans. Top intermixed through 1-in. zone. | 9.42 |
| 73 | Siltstone, fine- to coarse-grained, dark-gray (N3) to medium-dark-gray (N4). Top is parting plane. Massive graded bed in top 1 ft. Bottom interlaminated, braided, with some burrowing. Brachiopods and pelecypods at base. Eroded into underlying unit. | 3.33 |
| 72 | Siltstone, medium- to coarse-grained, medium-dark-gray (N4). Massive. Ripple-laminated. Lower 10 in. is a shell zone with channelled base. Also an upper shell zone. Top eroded. | 5.67 |
| 71D | Siltstone, coarse-grained, medium-dark-gray (N4). Massive. Structureless. Top eroded. | 4.76 |
| 71C | Siltstone, medium- to fine-grained, medium-dark-gray (N4). Massive. Upper half parallel laminated. Top burrow mottled and rippled. | 1.33 |
| 71B | Siltstone, medium- to fine-grained, to shale, medium-dark-gray (N4). Scoured base with brachiopods. | 1.33 |
| 71A | Siltstone, coarse- to medium-grained, medium-dark-gray (N4). Massive. Structureless. | 1.25 |
| 70 | Siltstone, fine- to coarse-grained, dark-gray (N3) to medium-dark-gray (N4). Braided. Abundant brachiopods in planar lenticular orientation. Burrow mottles in fine-grained siltstone. Top transitional. | 4.33 |
| 69 | Siltstone, coarse- to medium-grained, medium-dark-gray (N4). Massive. Structureless. Brachiopods (spirifers) near base. Three fossil and shale-chip zones near top in laminated, braided, and burrowed coarse- and fine-grained siltstone. Top burrow mottled and has brachiopod shells. | 4.42 |
| 68 | Siltstone, coarse- to medium-grained, medium-dark-gray (N4). Massive. Homogeneous mixture. Lower 1 ft. parallel laminated. Coarse-grained siltstone load casts in upper half. Scour channel with coarse-grained siltstone 2 ft. above base. Top sharp and flat. | 5.5 |
| 67 | Siltstone, coarse- to fine-grained, medium-dark-gray (N4). Massive. Upper third contains multiple interbeds of fine- to medium-grained siltstone and medium- to coarse-grained siltstone. Top sharp and wavy. | 6.80 |
| 66 | Siltstone, coarse- to medium-grained, dark-gray (N3) to medium-dark-gray (N4). Lower half load-casted. Some load casts oblique to bedding.Discontinuous zones and chips of siltstone. Braided in top 1 in.; grades into unit 67. | 2.68 |
| 65 | Siltstone, fine- to coarse- grained, dark-gray (N3) to medium-dark-gray (N4). Massive. Graded. Coarse-grained siltstone, parallel-laminated. Braided shale-chip horizon. Top loaded by unit 66. | 1.68 |
| 64 | Siltstone, coarse- to medium-grained, dark-gray (N3) to medium-dark-gray (N4). Massive. Top intermixed and braided. Brachiopod zone with fine-grained siltstone fragments in center. | 2.0 |
| 63 | Siltstone, medium- to coarse-grained, dark-gray (N3) to medium-dark-gray (N4). Coarse-grained siltstone in discontinuous lenses and load casts. Upper 2 ft. is interlaminated coarse- and fine-grained siltstone. Burrow mottling in fine-grained siltstone. Top sharp and wavy. | 12.42 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 62 | Siltstone, coarse- to medium-grained. Massive. Base is load casted. Parallel laminations in upper 3 ft. Middle contains zone of shale chips and brachiopods. Small steep crossbeds near top. Top sharp and flat. | 7.08 |
| 61 | Siltstone, fine- to medium-grained, medium-dark-gray (N4). Massive 3- to 12-in. beds. Grades in upper 1 in. to fine-grained siltstone. Some burrow mottling in fine-grained siltstone. Top sharp and loaded by unit 62. | 7.0 |
| 60 | Siltstone, coarse- to fine-grained, medium-dark-gray (N4). Massive. Structureless. Top 1 to 2 in. grades to fine-grained siltstone. | 7.16 |
| 59 | Siltstone, coarse- to fine-grained, medium-dark-gray (N4) to dark-gray (N3). Brachiopods at base. Trilobite cephalon 2.75 ft. above base, and spiriferid brachiopods. Coarse-grained siltstone parallel laminated. Burrow mottling in fine-grained siltstone filled with coarse-grained siltstone above. Top sharp and wavy. | 9.5 |
| 58 | Siltstone, coarse- to fine-grained, dark-gray (N3) to medium-dark-gray (N4). Nine graded beds. Coarse-grained siltstone comprises 75% of each. Contacts wavy and sharp. Coarse units in middle third form parallel laminations. Burrow mottles in fine-grained siltstone near top. Pyrite and brachiopods near top. Top sharp and wavy. | 2.08 |
| 57 | Siltstone, coarse- to fine-grained, medium-dark-gray (N4). Massive. Base load casted into unit 56. Coarse fraction structureless in lower half. Upper half all coarse-grained siltstone, parallel laminated. Cross-laminated near top. Brachiopod zone in middle. Pyrite near top. | 8.33 |
| 56 | Siltstone, fine- to coarse-grained, medium-dark-gray (N4). Several interbeds. Coarse-grained siltstone is parallel laminated. Fine-grained siltstone truncates coarse-grained siltstone. Burrows in fine-grained siltstone filled with coarse- grained siltstone. Top sharp, loaded. | 4.75 |
| 55 | Siltstone, coarse- to fine-grained, medium-dark-gray (N4) to dark-gray (N3). Massive. Grades to fine-grained siltstone in upper 1 in. Faint parallel laminations. Load casts and scoured surfaces. | 11.75 |
| 54 | Siltstone, coarse- to fine-grained, dark-gray (N3). Three graded repetitions, each with sharp wavy contacts. Top braided with overlying unit. | 1.5 |
| 53 | Siltstone, fine- to coarse-grained, dark-gray (N3) to medium-dark-gray (N4) to medium-gray (N5). Interbedded, interlaminated, and braided. Coarse-grained fraction parallel laminated. Contacts wavy and scoured. Top sharp and wavy. Sharp base. Pelecypods and trilobites near base. Many brachiopods in upper 9 in.—fossil zones. | 6.16 |
| 52 | Siltstone, fine- to coarse-grained, dark-gray (N3) to medium-dark-gray (N4). Interbedded, braided, and interlaminated. Coarse-grained siltstone dominant. Wavy and braided contacts. Load-cast zone 9 in. above base. Burrow mottles, tubes, and scattered fossils. | 13.75 |
| 51 | Siltstone, medium-grained, dark-gray (N3) to medium-dark-gray. Massive. Lower half structureless. Upper half parallel laminated and crossbedded. | 2.83 |
| 50 | Siltstone, fine- to coarse- grained, dark-gray (N3) to medium-dark-gray (N4). Interbedded, braided, and parallel-laminated. Coarse-grained siltstone dominant. Wavy contacts. Burrows and mud-filled tubes in upper 2 ft. Top sharp and wavy. | 14.5 |
| 49 | Siltstone, fine- to coarse-grained, dark-gray (N3) to medium-dark-gray (N4). Interbedded, interlaminated and contains lenticular zones. Fine fraction dominant. Has horizontal burrows and calcareous shells in lower 3 ft. Pyrite in middle. Scattered fossils in upper 3 ft. Top sharp and megarippled. | 17.0 |
| 48 | Siltstone, fine- to medium-grained, dark-gray (N3) to medium-dark-gray (N4). Channel flank. Massive. Medium-grained siltstone mixed with fine-grained siltstone and clayey silt. Parallel and wavy laminations. | 1.68 |
| 47C | Siltstone, coarse- to medium-grained, medium-dark-gray (N4). Massive and parallel laminated. Few shale chips. | 0.8 |
| 47B | Siltstone, fine- to coarse-grained, dark-gray (N3) to medium-dark-gray (N4). Interbedded and braided fine siltstone and medium to coarse siltstone. Parallel laminated. Wavy and lenticular beds. | 1.33 |
| 47A | Siltstone, coarse-grained, medium-gray (N5) to medium-light-gray (N6). Massive. Parallel laminated. | 1.25 |
| 46 | Siltstone, fine- to medium-grained, dark-gray (N3) to medium-gray (N5). Interlaminated and braided with wavy and rippled contacts. Sharp base and sharp wavy top. Two-in. lenticular shell zone of spirifers and other shells. | 4.08 |
| 45 | Siltstone, coarse- to medium- grained, medium-dark-gray (N4). Five pairs coarse-grained siltstone. Each begins with shale- and fossil-fragment zones which are interlaminated with overlying parallel-laminated medium- to coarse-grained siltstone. Shale-chip zones wedge out laterally into fine siltstone. | 3.16 |
| 44 | Siltstone, coarse- to fine-grained, medium-dark-gray (N4) to dark-gray (N3) to grayish-black (N2). Multiple interbeds of medium- to coarse-grained siltstone and fine-grained siltstone. Medium- and coarse-grained siltstone dominant. Some wavy bases and tops. Some burrow mottling. Discontinuous fossil zones in middle. Above are burrow mottles and pyrite. | 11.68 |
| 43C | Siltstone, coarse- and fine-grained, dark-gray (N3). Upper half is braided fine and coarse siltstone. | 0.68 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 43B | Siltstone, coarse-, medium-, and fine-grained, medium-dark-gray (N4) to dark-gray (N3). Lower half braided and interlaminated medium to coarse siltstone with fine siltstone. Upper half parallel-laminated coarse siltstone. | 0.68 |
| 43A | Siltstone, coarse-grained, medium-dark-gray (N4) to dark-gray (N5). Massive. Parallel laminated. | 1.08 |
| 42B | Siltstone, fine- and coarse-grained, dark-gray (N3) to medium-dark-gray (N4). Fine siltstone dispersed in coarse siltstone. Top undulatory. | 0.68 |
| 42A | Siltstone, medium- to fine-grained, medium-dark-gray (N4) to dark-gray (N3). Massive. Entirely parallel laminated. Base rippled. | 2.75 |
| 41 | Siltstone, medium- to coarse-grained, dark-gray (N3) to medium-dark-gray (N4). Load casts. Massive. Internally structureless. Parallel laminated in places. Some elongate slumps defined by fine-grained siltstone laminae. Sharp top. | 13.0 |
| 40 | Siltstone, medium- to coarse-grained, dark-gray (N3) to medium-gray (N5). Massive. Heterogeneous assemblages of bed types and grain sizes. Weathers sooty. Top sharp. Crinoids and brachiopods in upper third. Coarse-grained siltstone horizon in upper third in load casts. Medium-grained siltstone has bands, stringers, and lenses. Top sharp and interlaminated with overlying unit. | 20.75 |
| 39 | Siltstone, coarse- and fine-grained, medium-dark-gray (N4) to dark-gray (N3). Several pairs of interbeds. Lower part massive. Upper part has thin parallel lamination of fine to coarse siltstone. Coarse-grained siltstone dominant. | 9.33 |
| 38 | Siltstone, coarse- to medium-grained, medium-dark-gray (N4) to medium-gray (N5). Sharp top, slightly wavy. Abundant clay near top. Parallel and cross laminated. Shale chips. | 0.67 |
| 37G | Siltstone, fine-grained, dark-gray (N3). Sharp top. | 0.16 |
| 37F | Siltstone, coarse- and fine-grained, dark-gray (N3). Discontinuous laminations of fine-grained siltstone. | 0.6 |
| 37E | Siltstone, coarse-grained, medium-dark-gray (N4) to medium-gray (N5). Massive. | 1.75 |
| 37D | Siltstone, fine-grained, dark-gray (N3). | 0.08 |
| 37C | Siltstone, coarse-grained, medium-dark-gray (N4). Massive. Internally laminated. | 2.42 |
| 37B | Siltstone, fine-grained, dark-gray (N3). | 0.08 |
| 37A | Siltstone, coarse-grained, medium-gray (N5). Massive. | 1.5 |
| 36 | Siltstone, coarse- to fine-grained, medium-dark-gray (N4) to medium-gray (N5). Massive. Some parallel laminations. Crinoid columnals near middle. Fine- to medium-grained siltstone, interlaminated. Sooty. | 4.16 |
| 35 | Siltstone, coarse-grained, alternating with medium- to coarse-grained siltstone, dark-gray (N3) to medium-dark-gray (N4). Parallel-laminated. Scoured base. Top sharp, scoured. | 0.67 |
| 34D | Siltstone, coarse- to medium-grained, dark-gray (N3) to medium-dark-gray (N4). Parallel laminated. Coarse siltstone is dominant. | 0.5 |
| 34C | Siltstone, coarse-grained, medium-dark-gray (N4) to medium-gray (N5). Massive. | 2.67 |
| 34B | Siltstone, coarse- to medium-grained, dark-gray (N3) to medium-dark-gray (N4). Parallel laminations. | 0.5 |
| 34A | Siltstone, coarse-grained, medium-dark-gray (N4). Massive. | 13.3 |
| 33D | Siltstone, fine- to coarse-grained, medium-dark-gray (N4) to medium-gray (N5). Dominantly coarse siltstone; minor fine siltstone. | 0.33 |
| 33C | Siltstone, coarse- to medium-grained, medium-dark-gray (N4). Rippled top. | 2.16 |
| 33B | Siltstone, fine- to coarse-grained, medium-dark-gray (N4) to medium-gray (N5). Parallel laminations. Sharp top. | 0.25 |
| 33A | Siltstone, coarse- to medium-grained, medium-dark-gray (N4). Massive. Top rippled. Mud in ripple troughs. | 1.33 |
| 32 | Siltstone, coarse to fine-grained, medium-dark-gray (N4) to dark-gray (N3). Massive. Multiple graded beds 5 to 6 in. thick. Many wavy basal contacts. Parallel laminated. Horizontal burrows near middle. Top is parting plane. | 12.42 |
| 31 | Siltstone, fine- to medium-grained, dark-gray (N3). Lower half is thin bedded. Upper half has two graded beds. Gradational base. Sharp wavy top. | 1.16 |
| 30 | Siltstone, coarse- to fine-grained, medium-gray (N5) to dark-gray (N3). Massive. Multiple graded beds 6 in thick. | 12.67 |
| 29C | Siltstone, fine- and coarse-grained, dark-gray (N3) to medium-gray (N5). Massive. Graded. Parallel laminated. Rippled top. | 0.91 |
| 29B | Siltstone, medium- and fine-grained, medium-dark-gray (N4). Interlayers 0.5 in. thick. Parallel laminated. | 1.5 |
| 29A | Siltstone, coarse- to fine-grained, medium-dark-gray (N4) to dark-gray (N3). Massive. Graded. Upper half parallel laminated, and has shale chips and horizontal burrows. | 1.25 |
| 28 | Siltstone, coarse- to fine-grained, medium-dark-gray (N4). Five massive graded beds. Coarse-grained siltstone is dominant and is parallel laminated. Shell and shale fragments, horizontal burrows. | 9.0 |
| 27 | Siltstone, coarse- to fine-grained, medium-dark-gray (N4). Parallel-laminated near top. Upper contact diffuse. Massive in bottom. Pyrite-filled tubes in coarse-grained siltstone. | 1.83 |
| 26 | Siltstone, fine- to medium-grained, medium-dark-gray (N4) to medium-gray (N5). Massive; interbedded; parallel laminations, dominantly in medium-grained siltstone. Abundant horizontal burrows. Top 12 in. contains fossil fragments (brachiopods). | 4.68 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 25 | Siltstone, coarse- to medium-grained, medium-dark-gray (N4) to medium-gray (N5). Channel zone with fossils in lower 10 in. Multiple graded beds. Medium-grained siltstone dominant. Parallel laminated. Some pyrite. Top has parting planes. | 2.67 |
| 24 | Siltstone, coarse- to medium-grained, medium-dark-gray (N4) to medium-gray (N5). Massive. Horizontal burrows. Multiple graded beds. Medium-grained siltstone dominant. Fossil zones with carbonate-filled molds near base. Upper contact wavy, sharp. | 7.68 |
| 23 | Siltstone, coarse- to medium-grained, medium-dark-gray (N4) to medium-gray (N5). Top rippled, has plants, pyrite, and some graded beds. Center is parallel laminated. Base is massive. | 2.16 |
| 22 | Siltstone, coarse- to medium-grained, medium-dark-gray (N4). Horizontal burrows. Multiple graded beds poorly organized due to burrowing. Top is sharp and wavy. | 3.33 |
| 21 | Siltstone, coarse- to medium-grained, medium-dark-gray (N4) to medium-gray (N5). Massive. Multiple graded beds 2 to 4 in. thick. Medium-grained siltstone dominates lower half. Coarse-grained siltstone dominant in upper half. Burrow mottles and crinoid columnals in lower half. Upper half has horizontal burrows and discontinuous horizon of fossils. Top is a parting plane. | 11.5 |
| 20 | Siltstone, coarse- to medium-grained, medium-dark-gray (N4). High clay content. Minor coarse-grained siltstone. Poor sorting. Sharp top with plant imprints. | 1.08 |
| 19 | Siltstone, coarse- to medium-grained, medium-dark-gray (N4). Top half: 1-in. graded beds with plant imprints. Bottom half: massive, graded, minor medium-grained siltstone. Top of upper half is rippled fine siltstone containing plant impressions. | 2.92 |
| 18 | Siltstone, medium- to coarse-grained, dark-gray (N3) to medium-gray (N5). Multiple 1-in. graded beds. Medium-grained siltstone dominant. Most coarse-grained siltstone is parallel laminated; some is lenticular. Horizontal burrows, brachiopods, and carbonaceous material near top. Sharp top. | 32.16 |
| 17 | Siltstone, fine- and coarse-grained, medium-dark-gray (N4). Blocky. Multiple coarse- to fine-grained siltstone beds. Ten couplets of 8-in. coarse-grained siltstone and 1-in. fine-grained siltstone sets. Top burrow mottled. Parallel laminations. | 11.0 |
| 16 | Siltstone, medium-grained, dark-gray (N3). Massive. Scattered fossils. | 4.0 |
| 15 | Siltstone, fine- to coarse-grained, medium-dark-gray (N4). Blocky. Fine- and medium-grained siltstone, mixed. Small amount of coarse-grained siltstone, parallel-laminated, with sharp bases and tops. Brachiopod zone 6 in. below top. | 9.67 |
| 14 | Siltstone, fine- to coarse-grained, dark-gray (N3) to medium-dark-gray (N4). Massive. Fossils. Several graded beds. Burrow mottles in coarse-grained siltstone. Horizontal burrows. Parallel laminations in some graded beds. Crinoids and brachiopods in upper 1 in. | 7.67 |
| 13 | Siltstone, coarse- to fine-grained, medium-dark-gray (N4). Beds increasingly massive upward; one to 3 in. thick below and 4 to 6 in. thick above. Several graded beds. Bottom massive, top parallel laminated. Top contact sharp. | 4.75 |
| 12 | Siltstone, coarse- to fine-grained, medium-dark-gray (N4). Three graded beds in lower 1½ in. Coarse-grained siltstone is parallel laminated. Top sharp, scoured. Shale chips in upper contact. | 0.91 |
| 11 | Siltstone, coarse- to medium-grained, dark-gray (N3). Rust zones with sharp bases and gradational tops. Few burrows in lower half. Crinoid columnals and brachiopod imprints near base. | 9.08 |
| 10 | Siltstone, coarse- to fine-grained, dark-gray (N3) to medium-gray (N5). Top 13 in. massive, with parallel and cross laminations. Sharp top. Bottom 8¼ ft. has parallel 1- to 4-in. beds. Sharp base and top. Small amount of fine-grained siltstone. Lower half is parallel laminated in part. Upper part has 7 graded beds. | 9.33 |
| 9 | Siltstone, coarse-grained, brownish-gray (5YR4/1). Lenses to 4 in., massive. Sharp base and top. | 0.67 |
| 8 | Siltstone, medium-grained, dark-gray (N3). Massive 1- to 2-in. blocky beds. Few ½- to 1-in. coarse-grained siltstone beds. Some burrowed; a few have parallel laminations. Tracks and trails and brachiopod imprints 2 ft. below top. | 4.91 |
| 7 | Siltstone, coarse-grained, dark-gray (N3). Massive. Sharp base and top. | 0.42 |
| 6 | Siltstone, coarse- to fine-grained, dark-gray (N3). Three pairs graded beds, each 1 to 2 in. thick. Base and top sharp. Parallel laminations at base cut by crossbedded unit above. Fossils (brachiopods) in top 6 in. | 5.25 |
| 5 | Siltstone, coarse-grained, dark-gray (N3). Massive. Sharp base. Top interlaminated through a ⅛-in. zone. | 0.67 |
| 4 | Sandstone, very fine grained and siltstone, coarse- to medium-grained. Many laminated zones. Several very fine grained sandstone beds 1 to 2 in. thick. Gray-white carbonaceous zones. Blocky beds. Few fossils. Mottled sandstone. Siliceous nodules at top. | 75.0 |
| 3 | Sandstone, very fine grained, and siltstone, coarse- to medium-grained, dark-gray (N3) to medium-dark-gray (N4). More massive than unit 2. Massive units are 2 to 4 in. thick. Micro-scour-and-fill structures and cross laminations. Carbonaceous zone near top. | 109.0 |
| 2 | Siltstone, coarse- to medium-grained, dark-gray (N3) to medium-dark-gray (N4). Platy and fissile. | 39.0 |
| 1 | Shale and siltstone, coarse- to medium-grained, medium-dark-gray (N4). Incomplete exposure. | 146.0 |
|  | Total | 1,056.37 |

## SECTION 9

# TOWAMENSING MEMBER OF CATSKILL FORMATION

Type section of the Towamensing Member of the Catskill Formation, located in a roadcut on Pa. Route 248 between Bowmanstown and Parryville on the east bank of the Lehigh River in Lower Towamensing Township. Base of section is 5,900 feet north of latitude 40°47′30″ and 810 feet west of longitude 75°40′ (Figure 93). The base of the section at road level occurs at a culvert, adjacent to a road sign which reads "Lehighton 3 miles: Jim Thorpe 7 miles." The Tully fossil horizon lies to the south. Section measured by J. D. Glaeser.

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 81B | Sandstone, fine-grained, medium-bluish-gray (5B5/1) to medium-dark-greenish-gray (5G5/1). Siliceous cement. Mottling. Dominantly medium-light-brownish gray (5YR5/1). Top 1.33 ft. grades upward to red color and into Walcksville Member. | 2.33 |
| 81A | Sandstone, fine- to medium-grained, medium-bluish-gray (5B5/1) to medium-dark-greenish-gray (5G5/1). Sharp planar base. Quartzitic. Massive, structureless. | 4.67 |
| 80 | Siltstone, coarse-grained, medium-dark-gray (N4). Base sharp and planar. Lower 0.16 ft. flaggy, high clay and disseminated carbon content. | 1.16 |
| 79 | Sandstone, very fine grained, to siltstone, coarse-grained, medium-dark-gray (N4) to medium-gray (N5). Coaly plant fragments. Top ½ in. is coaly sandstone. Planar beds. Massive. Tough. Weathers black, yellow, and rust. | 0.83 |
| 78 | Sandstone, very fine grained, to siltstone, coarse-grained, medium-gray (N5). Massive. Tough. No planar structures. Lower 2.67 ft. interfingers with unit 77. Interfingering beds are fine-grained siltstone, medium-dark-gray (N4). | 12.67 |
| 77 | Siltstone, medium-grained, olive-gray (5Y4/1). Sharp planar top interfingers with unit 78. No break above unit 76. | 0.67 |
| 76 | Sandstone, fine- to very fine grained, and siltstone, fine-grained. Sandstone is medium gray (N5); siltstone is olive gray (5Y4/1). Sharp basal contact. A shale layer grades up through 1 mm to sandstone. Sandstones are alternating, discontinuous lenses and layers. Wavy bedding; sand-filled knots. | 1.42 |
| 75 | Sandstone, very fine grained, medium-gray (N5). Flow contortion at top; shale chips on end. Swirls of sand in sand. Massive. Tough. Conglomeratic at base. Base scoured; up to 6 in. of relief. | 1.42 |
| 74 | Siltstone, medium-, grading up to fine-grained, medium-dark-gray (N4). Top 1 in. grades to fine-grained siltstone. Flaggy. | 1.5 |
| 73 | Sandstone, very fine to fine-grained, medium-gray (N5). Upper 2 to 3 ft. grades into coarse-grained siltstone. Alternating beds of very fine to fine-grained sandstone and very fine to fine-grained sandstone with shale fragments, dark-gray (N3) to medium-dark-gray (N4). Shale fragments are parallel to beds. Base is calcareous, leached, plant-bearing. | 7.83 |
| 72 | Sandstone, fine- to medium-grained, medium-gray (N5). Massive. Tough. Multiple minute laminae in center. | 4.50 |
| 71 | Sandstone, medium-grained, medium-light-gray (N6). Shale fragment conglomerate, intimately mixed with sandstone. Scours unit 70 with 6 in. of relief. Near base, sandstone is interbedded with shale. | 1.5 |
| 70 | Sandstone, fine-grained, medium-gray (N5) to medium-light-gray (N6). Massive, structureless. Where plant zone absent at top of unit 69, there is no parting plane between units. Basal 2 in. bleached by plant material of unit 69. | 5.16 |
| 69B | Sandstone, fine- to medium-grained, medium-gray (N5) to medium-light-gray (N6). Massive. Structureless. Top 2 in. bleached and rusty. Top surface has coaly plant material. Base defined by cessation of shale clasts of unit 68. No grain size change in the sandstone. | 2.16 |
| 69A | Sandstone, fine- to medium-grained, medium-light-gray (N6). Shale fragments throughout. Liesegang banding in unit near top. Large (8 in. x 3 in. max.) olive-gray shale clasts at base. | 1.24 |
| 68 | Sandstone, fine-grained, medium-light-gray (N6). Massive, planar base, tough. | 0.25 |
| 67 | Sandstone, fine-grained, medium-gray (N5). Planar beds, dark shale-chip zone near middle. Coaly fragments at top. | 0.33 |
| 66 | Sandstone, medium- to fine-grained, medium-dark-gray (N4). Planar base. Very tough, silica cemented. Coaly seam marks top. | 0.66 |
| 65 | Siltstone, fine-grained, to shale, and sandstone, fine- to very fine grained. Sandstone is medium gray (N5); shale and siltstone are dark gray to medium-dark gray (N3-N4). Discontinuous shale-siltstone laminae; base is planar. | 0.5 |
| 64 | Sandstone, very fine grained, medium-gray (N5). Massive, tough. Undulatory base, but no erosion evident. Shale lamina containing plant impressions caps the top. | 0.92 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 63 | Two pairs of coarse- and finer grained units. Lower pair consists of coarse siltstone (0.67 ft. thick) overlain by 0.08 ft. of fine siltstone, medium-dark-gray (N4). The upper pair consists of sandstone, very fine grained (0.16 ft. thick), medium-gray (N5), overlain by 0.16 ft. of shale, medium-dark-gray (N4). | 1.07 |
| 62 | Siltstone, coarse-, medium-, and fine-grained, dark-greenish-gray (5GY4/1) and medium-dark-gray (N4). | 2.16 |
| 61 | Siltstone, coarse-, medium-, and fine-grained, very dark greenish gray (5GY3/1) and medium-dark-gray (N4). Micaceous. Multiple thin interbeds. | 4.92 |
| 60 | Three gradational successions of sandstone fining up through siltstone, coarse- to medium- to fine-grained. The upper of the three is 1.8 ft. thick; the lower two are each 0.16 ft. thick. Finer portion is dark gray (N3); coarse portion is medium-dark-gray (N4). | 2.15 |
| 59 | Sandstone, very fine grained, and siltstone, coarse-, medium- and fine-grained, dark-gray (N3) (finer units) to medium-dark-gray (N4) ( coarser units). Top ¼ in. rippled. Burrows, burrow mottling, and trails. | 1.42 |
| 58 | Sandstone, very fine grained, to siltstone, coarse-, medium-, and fine-grained. Several interbeds; basal 0.16 ft. is fine siltstone. Finer units are medium-dark gray (N4); coarser units are medium gray (N5). Top layer may be rippled. | 1.41 |
| 57 | Sandstone, very fine grained, grading up in several interbeds to siltstone, coarse-, medium-, and fine-grained, and to shale. Finer units are dark gray to medium-dark gray (N3-N4); coarser units are medium gray (N5). Massive; no laminations. Laminated at base. | 1.40 |
| 56 | Siltstone, medium-grained, dark-gray (N3) to medium-dark-gray (N4). Tough. Incipient fissility in lower half. No physical break with unit 55. | 1.42 |
| 55 | Siltstone, coarse- to medium-grained, medium- dark-gray (N4). Tough. Basal 0.02 ft. has medium to coarse, glassy quartz grains. | 0.42 |
| 54 | Siltstone, medium- and coarse-grained, medium-dark-gray to medium-gray (N4-N5). Base scours unit 53, 0.5-ft. relief. Particles of quartz in lower 1 in. | 1.17 |
| 53 | Sandstone, fine- to very fine grained, medium-light-gray (N6). Top eroded. Tough. Abundant large coaly plant fragments. Wedge-shaped and irregular-shaped beds. | 3.33 |
| 52 | Sandstone, very fine grained, medium-light-gray (N6). Undulatory base and top, 4-in. relief. May be postdepositional compaction. Massive. Tough. Coaly plant fragments. | 2.16 |
| 51 | Siltstone, medium- to coarse-grained, medium-dark-gray (N4) to medium-gray (N5). Medium-grained siltstone and shale in lower 2.16 ft. Well sorted. Tough. Some internal layering. Four aligned, deeply weathered zones. | 4.99 |
| 50 | Siltstone, medium-grained, grading up through fine siltstone to shale, medium-gray (N5) to medium-light-bluish-gray (5B6/1). White coating in upper 2 ft. Incipient laminated character increases upward. Undulatory base. Massive. | 5.16 |
| 49 | Siltstone, medium-grained, medium-dark-gray (N4) to medium-gray (N5). Long plant imprint and 2-ft.-long plant remnant near top. Entire unit may be a lens. Trough-like beds. Coaly material at base. Base undulatory. | 1.33 |
| 48 | Siltstone, coarse- to medium-grained, medium-gray (N5). Coaly plant-bearing layer 5 in. above base. Wavy base. Carbonaceous material suggested by rust, yellow, and white colors. | 1.25 |
| 47 | Sandstone, very fine grained, to siltstone, coarse-grained, medium-dark-gray (N4). Massive. Base irregular; no erosion evident. Top surface contains coaly plant material. | 1.16 |
| 46 | Siltstone, coarse- to medium-grained, medium-dark-gray (N4). Abundant clay and calcareous material, increasing upward. External colors are green, dark red, white, and rust. | 3.33 |
| 45 | Siltstone, medium-grained, medium-dark-gray (N4). Hackly fracture. Stained white and dirty olive. Upper 3 in. is fissile and contains carbonaceous material. | 3.0 |
| 44 | Siltstone, fine-grained, to shale, dark-gray (N3). Lower 1 in. is faulted and coaly. | 1.33 |
| 43 | Siltstone, fine-grained, with two lenses of coarse-grained siltstone in middle portion, dark-gray (N3) to medium-dark-gray (N4). In basal 0.08 ft., incipient cleavage intersects bedding to produce a hackly fracture. | 2.49 |
| 42 | Sandstone, fine-grained, medium-gray (N5). Well-developed ripple marks in upper 4 in. Plant impressions. Sharp base. | 0.83 |
| 41 | Quartzitic sandstone, medium-dark-gray (N4). Slightly wavy base; 1-in. zone of shale chips just above base. Pyrite present in lower half. | 0.42 |
| 40 | Siltstone, coarse- to medium-grained, medium-gray (N5) to medium-light-gray (N6). Scattered pyrite; plant remains. | 1.16 |
| 39 | Siltstone, medium- to fine-grained, medium-light-gray (N6). Quartzitic. | 1.84 |
| 38 | Sandstone, very fine grained, to siltstone, coarse- to medium-grained, dark-gray (N3) to medium-dark-gray (N4). Sandy beds are burrowed. Mud cracks are sand filled. Rust-colored zones. Interlayered. | 7.0 |
| 37 | Siltstone, coarse- to medium-grained, medium-dark-greenish-gray (5GY5/1) to medium-gray (N5). Base not well defined. Massive. Nonplanar. Increasing clay content in top 1 ft. | 3.75 |
| 36 | Sandstone, very fine grained, and siltstone, coarse-grained, medium-gray (N5). Massive. Nonplanar. Sharp base. | 2.25 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 35 | Sandstone, very fine grained, medium-dark-gray (N4). Basal and top laminae are siltstone, medium-grained, medium-light-bluish-gray (5B6/1). | 0.60 |
| 34 | Sandstone, very fine grained, medium-gray (N5). Massive. | 1.08 |
| 33 | Sandstone, fine- to very fine grained, grading up into siltstone, coarse- to medium-grained, medium-dark-gray (N4) to medium-gray (N5) to medium-light-bluish-gray (5B6/1). Top surface rippled. | 1.42 |
| 32 | Alternating beds of sandstone, fine- to very fine grained, medium-gray (N5), and siltstone, medium-grained, medium-dark-gray (N4). Base is sharp. | 0.64 |
| 31–30 | Sandstone, fine-grained, medium-dark-gray (N4) to medium-gray (N5), interbedded with shale-chip conglomerate, dark-gray (N3). Massive fine-grained sandstone. Rusty plant remains near base. Irregular base. | 11.17 |
| 29 | Sandstone, fine- to very fine grained, medium-gray (N5). Slight size decrease upward. Massive. Dark siltstone or carbonaceous chips near top. Dark rusted laminations near center. | 3.58 |
| 28 | Sandstone, very fine grained, medium-dark-gray (N4). Sharp base. Massive. Top 0.04 ft. is siltstone, fine-grained, dark-gray (N3); contains plant remains. | 1.50 |
| 27 | Sandstone, fine- to very fine grained, medium-dark-gray (N4), with thin, discontinuous medium-grained siltstone bed near middle. Carbonaceous. Remainder of unit massive and tough. Top contains plant impressions. | 1.16 |
| 26 | Sandstone, medium- to fine- to very fine grained, medium-gray (N5). Tough. Massive. Nonplanar. Top 0.08 ft. is medium-grained, carbonaceous siltstone. | 6.08 |
| 25 | Sandstone, fine-grained, medium-dark-gray (N4). Massive. Tough. | 2.33 |
| 24 | Sandstone, fine-grained, medium-dark-gray (N4). Base not clearly defined. Rust-colored layers. Unit is massive and tough. | 0.5 |
| 23 | Sandstone, very fine grained, grading up into siltstone, coarse-grained, medium-dark-gray (N4). Massive. Tough. Nonplanar. | 3.58 |
| 22 | Sandstone, very fine grained, medium-dark-gray (N4). Tough. Plant(?) impressions on top. Massive, nonplanar. | 4.0 |
| 21 | Shale, dark-gray (N3), thoroughly mixed and contorted, with fine-grained sandstone, medium-gray (N5). Churned and mixed basal contact. Top very irregular with horizontal burrows. | 0.83 |
| 20–17 | Siltstone, fine- to medium-grained, dark-gray (N3) to medium-gray (N5). Multiple paper-thin laminations at top. Rusted carbonaceous zone below, with undulatory base, minute alternations. Massive nonplanar conchoidal fracture at base. | 4.09 |
| 16 | Seven graded beds, each consisting of sandstone, fine- to very fine grained, grading up into siltstone, coarse-grained. Base of sequence is undulatory. Base of each graded bed is sharp. Color ranges from medium-light gray in the coarsest fraction to medium-dark gray (N4) in the finer fraction. | 0.24 |
| 15 | Siltstone, medium-grained, medium-dark-gray (N4). Massive. Sharp and undulatory base. Nonplanar. | 0.25 |
| 14 | Sandstone, medium- to fine-grained. Undulatory base. Dark shale chips just above base. | 1.67 |
| 13 | Sandstone, fine- to very fine grained, medium-gray (N5). 0.81 ft. interlaminated with siltstone, medium-grained, medium-dark-gray (N4). | 0.85 |
| 12 | Siltstone, coarse- to medium-grained, medium-dark-gray (N4). Massive. Plant remains. | 4.08 |
| 11 | Siltstone, coarse- to medium-grained, medium-dark-gray (N4). Multiple internal laminations. | 0.37 |
| 10 | Siltstone, coarse- to medium-grained, medium-dark-gray (N4). Contorted mixture. | 1.16 |
| 9 | Siltstone, medium-grained, medium-dark-gray (N4). Conchoidal fracture. No planar elements. | 5.58 |
| 8 | Siltstone, medium- and coarse-grained, to sandstone, very fine grained, medium-dark-gray (N4). Layers of siltstone with very thin layers and laminae of coarse siltstone to very fine sandstone. | 0.91 |
| 7 | Sandstone, very fine grained, medium-gray (N5). Few discontinuous limonite-stained layers 3 in. from top. Base sharp. Unit is slightly finer and darker than underlying unit 6. | 0.92 |
| 6 | Sandstone, fine- to very fine grained, medium-gray (N5). Massive. Base minutely scoured and mixed with underlying bed. | 2.5 |
| 5 | Sandstone, very fine grained, and siltstone, medium-grained, medium-dark-gray (N4). Zebra-striped iron stain and alternations. Few scattered lenticular shale fragments; pyrite present 6 in. below top. Planes of lamination slightly inclined to plane of basal surface. Base sharp. | 0.5 |
| 4 | Sandstone, fine- to very fine grained, medium-gray (N5), to siltstone, coarse-grained, medium-dark-gray (N4). | 0.45 |
| 3 | Sandstone, very fine grained, medium-dark-gray (N4). Tough. Some laminae are limonite stained. Undulatory base. Multiple laminations. | 2.0 |
| 2 | Sandstone, very fine grained, siltstone, medium-grained, and shale, dark-gray (N3) to medium-dark-gray (N4). Jumbled mixtures of blocks up to 2 ft. long. No planar structures. Slump zone. | 5.5 |
| 1 | Sandstone, very fine grained, medium-dark-gray (N4). Massive. Sharp erosional and loaded base. Base of unit in sharp contact with Trimmers Rock Formation. | 4.0 |
|  | Total | 189.58 |

## SECTION 10

## WALCKSVILLE MEMBER OF CATSKILL FORMATION

Reference section of the Walcksville Member of the Catskill Formation, located in a roadcut in the Indian Hills on the east bank of the Lehigh River north of Weissport (Figure 100). Base of section is 5,100 feet north of latitude 40°51′ and 300 feet east of longitude 75°42′30″. Section measured by J. D. Glaeser.

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 73 | Siltstone, medium-grained, grayish-red (5R4/2). Fracture cleavage; fissile. Top of unit is in contact with Beaverdam Run Member. | 3.0 |
| 72 | Interbeds of siltstone, medium-grained, pale-red (5R6/2), blocky, and shale to siltstone, fine-grained, fissile, grayish-olive (10Y4/2). | 1.65 |
| 71 | Siltstone, coarse-grained, grayish-olive (10Y4/2) to greenish-gray (5GY6/1) in the lower 1.16 ft. Massive. Laminated in the lower 1.16 ft.; above this, unit has platy to incipient fissility. | 5.67 |
| 70 | Siltstone, medium-grained, medium-light-olive-gray (5Y5/1). Massive, incipient fissility. Upper 0.16 ft. is fine-grained siltstone, grayish-olive (10Y4/2). | 4.5 |
| 69 | Sandstone, very fine grained, to siltstone, coarse-grained, light-olive-gray (5Y6/1) to greenish-gray (5GY6/1). Massive, blocky. | 3.67 |
| 68 | Siltstone, medium- to coarse-grained, moderate-olive-brown (5Y4/4), massive. Upper 1.66 ft. is siltstone, medium-grained, light-olive-gray (5Y6/1), fissile. | 2.33 |
| 67 | Sandstone, very fine grained, grades to siltstone, coarse-grained, light-bluish-gray (5B7/1) to light-olive-gray (5Y6/1). Massive. Upper 1.7 ft. is medium-grained siltstone, pale-grayish-olive (10Y5/2), fissile. | 2.5 |
| 66 | Siltstone, medium-grained, grayish-red (5R4/2). Ripples 2 ft. below top on underside of bed; blocky; fracture fissility. | 9.5 |
| 65 | Siltstone, coarse- to fine-grained, pale-olive (10Y6/2). Graded bed. Color transition in upper 1 in. Fissility increases upwards. | 3.0 |
| 64 | Covered. | 114.2 |
| 63 | Siltstone, medium-grained, greenish-gray (5G6/1). High clay content. | 2.0 |
| 62 | Siltstone, coarse- to medium-grained, grayish-red (5R4/2). Upper few feet mottled with green. Several alternating units. | 23.2 |
| 61 | Siltstone, medium- to fine-grained, medium-light- olive-gray (5Y4/2). Top of basal 0.25 ft. capped by mud-cracked veneer. Top two-thirds is leached. | 2.0 |
| 60 | Siltstone, fine- to coarse-grained, grayish-red (5R4/2). Tracks and trails; few green mottles at top. | 18.5 |
| 59D | Siltstone, coarse- to medium-grained, grayish-red (5R4/2). Fracture fissility. | 2.0 |
| 59C | Siltstone, coarse-grained, grayish-red (5R4/2). | 1.25 |
| 59B | Siltstone, coarse- to medium-grained, grayish-red (5R4/2). Fracture fissility. | 3.0 |
| 59A | Siltstone, coarse-grained, grayish-red (5R4/2). | 2.0 |
| 58 | Sandstone, very fine grained, upper half is grayish red (5R4/2) and bottom half is dusky yellow (5Y6/4). Color transition with no physical break. | 17.4 |
| 57 | Covered. | 4.7 |
| 56 | Siltstone, fine- to medium-grained, light-olive-gray (5Y5/2). One ft. above base is a 13.4-ft. unit of siltstone, medium- to coarse-grained, grayish-red (10R4/2). | 17.4 |
| 55 | Sandstone, very fine grained, to siltstone, coarse- grained, dusky-yellow (5Y5/4—5Y6/4). Flaggy. | 9.6 |
| 54B | Covered. Float similar to underlying unit. | 19.3 |
| 54A | Sandstone, fine- to very fine grained, to siltstone, coarse-grained, dark-yellowish-gray (5Y6/2). | 18.1 |
| 53 | Covered. | 2.67 |
| 52 | Siltstone, coarse-grained, light-olive-gray (5Y5/2). Fracture cleavage. Increasing clay content upward. | 3.67 |
| 51 | Siltstone, coarse-grained, dark-grayish-red (5R3/2). Fracture cleavage. Upper few feet has increasing clay content. | 16.4 |
| 50 | Siltstone, coarse- to medium-grained, dusky-yellow (5Y6/4) to moderate-olive-brown (5Y4/4). Fractured. | 5.5 |
| 49 | Siltstone, coarse-grained, to sandstone, very fine grained, dusky-yellow (5Y5/4). Massive to flaggy; internal laminations. | 4.33 |
| 48 | Covered. | 5.7 |
| 47 | Two pairs of fining-upward sequences of siltstone, coarse- to medium-grained, and shale, grayish-red (5R4/2). Upper 1.5 ft. is moderate-olive brown (5Y4/4). | 6.7 |
| 46 | Siltstone, coarse-grained, light-grayish-red (5R5/2). Massive. | 1.0 |
| 45 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2). Partly covered. | 12.5 |
| 44 | Siltstone, medium-grained, dusky-yellow (5Y5/4). Fracture cleavage. | 1.5 |
| 43 | Covered. | 3.0 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 42 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2) to dark-grayish-red (5R3/2). Upper 3.5 ft. is siltstone, medium-grained, light-olive-gray (5Y5/2), with prominent fracture cleavage. | 15.4 |
| 41 | Sandstone, very fine grained, to siltstone, coarse-grained, light-grayish-red (5R5/2). Massive. | 0.67 |
| 40 | Siltstone, fine- to medium-grained, medium-reddish-brown (10R4/4). Fracture cleavage. | 3.75 |
| 39 | Siltstone, coarse-grained, grayish-red (5R4/2). Platy in mid third. | 1.5 |
| 38 | Shale to siltstone, fine-grained, grayish-red (5R4/2) with light-olive-gray (5Y6/1). Mottling in mid third. | 3.0 |
| 37 | Covered. | 1.33 |
| 36 | Siltstone, coarse-grained, grayish-red (5R4/2). Massive. | 3.33 |
| 35 | Siltstone, medium-grained, grayish-red (5R4/2). Fracture cleavage. | 4.67 |
| 34 | Siltstone, coarse-grained, pale-grayish-red (5R5/2). Massive. | 3.5 |
| 33 | Siltstone, medium-grained, to sandstone, very fine grained, dark-grayish-red (5R3/2) to light-grayish-red (5R5/2). Incipient fissility. | 1.16 |
| 32 | Siltstone, coarse- to medium-grained, grayish-red (5R4/2). Coarse-grained siltstone stringers. | 2.5 |
| 31 | Siltstone, medium- to fine-grained, light-grayish-olive (10Y5/2). Color transition at top. Lower 0.25 ft. leached. | 2.0 |
| no #30 | | |
| 29 | Shale to siltstone, medium-grained, light-olive-gray (5Y5/2). Fracture fissility. Grain size coarsens upward. | 4.33 |
| 28 | Siltstone, coarse-grained, to sandstone, very fine grained, yellowish-gray (5Y7/2) to pale-olive (10Y6/2). Flaggy to massive. | 3.33 |
| 27 | Shale to siltstone, medium-grained, pale-olive (10Y6/2) to mottled-grayish-red (10R4/2). Lower 0.75 ft. is grayish red (10R4/2). Incipient fissility, fracture cleavage. | 3.83 |
| 26 | Siltstone, coarse- to medium-grained, grayish-red (5R4/2—10R4/2). Massive. Top 6 in. has incipient fissility. | 3.33 |
| 25 | Siltstone, fine-grained, moderate-red (5R4/4). Fracture fissility. | 3.0 |
| 24 | Siltstone, medium- to fine-grained, grayish-red (5R4/2) to dark-grayish-red (5R3/2). Incipient fissility in the top 4.0 ft. | 5.5 |
| 23 | Sandstone, very fine grained, to siltstone, very coarse grained, grayish-red (5R4/2). | 1.5 |
| 22 | Sandstone, very fine grained, grading up into siltstone, coarse- to medium-grained, grayish-red (5R4/2) to light-grayish-red (5R5/2). Siltstone chips. Desiccation cracks in top layer. | 1.5 |
| 21 | Siltstone, fine-grained, grayish-red (5R4/2) to dark-grayish-red (5R3/2). Incipient fissility. | 7.0 |
| 20 | Sandstone, very fine grained, grayish-red (5R4/2). | 0.33 |
| 19 | Siltstone, fine-grained, dark-grayish-red (5R3/2). | 0.08 |
| 18 | Sandstone, very fine grained, to siltstone, coarse-grained, grayish-red (5R4/2). Upper half contains fine siltstone, dark-grayish-red (5R3/2). | 0.16 |
| 17 | Siltstone, fine-grained, dark-reddish-brown (10R3/4). Incipient fissility. | 1.25 |
| 16 | Sandstone, very fine grained, to siltstone, coarse-grained, pale-grayish-red (5R5/2). Massive. | 1.0 |
| 15 | Siltstone, medium-grained, grading up into fine-grained, moderate-dusky-red (5R3/4). Fissile. | 6.5 |
| 14 | Siltstone, coarse-grained, to sandstone, very fine grained, grayish-red (10R4/2). Massive. | 3.0 |
| 13 | Siltstone, fine-grained, dark-grayish-red (5R3/2). Platy; large pencil fragments. | 3.0 |
| 12 | Sandstone, very fine grained, grayish-red (5R4/2). | 3.0 |
| 11 | Covered. | 2.0 |
| 10 | Sandstone, very fine grained, pale-olive (10Y6/2) to light-olive-gray (5Y6/1). Blocky and flaggy. | 8.5 |
| 9 | Covered. | 1.5 |
| 8 | Siltstone, coarse-grained, and shale to siltstone, fine-grained, medium-light-olive (10Y4/4) to pale-olive (10Y6/2). Laminated and interbedded. | 5.0 |
| 7 | Siltstone, fine-grained, grayish-red (10R4/2). | 0.75 |
| 6 | Shale to siltstone, fine- to medium-grained, light-olive-gray (5Y5/2). Upper half is clay-rich, mottled, silty mudstone, moderate-greenish-yellow (10Y6/4). | 9.7 |
| 5B | Sandstone, very fine grained, medium-dark-greenish-gray (5Y5/1). Some beds massive. Flaggy. Internally laminated. | 24.8 |
| 5A | Covered. | 24.8 |
| 4 | Shale to siltstone, medium-grained, dusky-yellow (5Y6/4). Float made up of pencil fragments. | 7.0 |
| 3B | Siltstone, coarse-grained with dominant sandstone, dark-yellowish-gray (5Y6/2) with grayish-red (5R4/2) siltstone. | 18.5 |
| 3A | Shale and siltstone, medium-grained, with dominant sandstone, pale-olive (10Y6/2). Shale chips, dark-yellowish-gray (5Y6/2). Minor siltstone, pale-reddish-brown (10R5/4). | 18.5 |
| 2D | Siltstone, coarse-grained, greenish-gray (5GY6/1). | 8.0 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 2C | Siltstone, medium-grained, and interbedded sandstone, very fine grained, medium-olive-gray. | 13.0 |
| 2B | Sandstone, very fine grained, medium-dark-greenish-gray (5GY5/1). | 20.5 |
| 2A | Quartzitic sandstone with fine siltstone clasts, very pale orange (10YR8/2). | 1.5 |
| 1B | Siltstone, coarse- to medium-grained, moderate-brown (5YR4/4), grayish-red (10R4/2), and medium-reddish-brown (10R4/4). Occurs in float. | 11.0 |
| 1A | Siltstone, coarse-grained, and sandstone, very fine grained, light-olive-gray (5Y5/2). Siltstone minor (May be red float 122 feet stratigraphically below this unit.) | 22.0 |
| | Total | 644.94 |

## SECTION 11

# BEAVERDAM RUN MEMBER OF CATSKILL FORMATION

Reference section of the Beaverdam Run Member of the Catskill Formation, located on the west side of U.S. Route 209 just south of Beaverdam Run on the west bank of the Lehigh River between the towns of Jamestown and Packerton (Figure 101). Base of section is 5,380 feet north of latitude 40°50′ and 1,100 feet west of longitude 75°42′30″. Section measured by J. D. Glaeser.

The name Beaverdam Run was proposed by Klemic and others (1963) and is used, as defined by them, in this report. The Beaverdam Run Member of the Catskill Formation is not the same as the Middle Devonian Beaver Dam Member, defined by Willard and others (1939, p. 141, 153) and used subsequently by Dennison (1961).

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| | APPROXIMATELY 194′ OF COVER LIES ABOVE UNIT 202 AND IS INCLUDED IN THE BEAVERDAM RUN MEMBER. | 194.0 |
| 202 | Siltstone, fine-grained, dusky-yellow (5Y5/4). Fissile. | 5.0 |
| 201 | Siltstone, coarse-grained, dark-yellowish-gray (5Y6/2). Massive, spheroidal weathering. | 0.67 |
| 200 | Siltstone, fine-grained, medium-light-olive-gray (5Y4/2). | 2.0 |
| 199 | Siltstone, coarse-grained, medium-light-olive-gray (5Y5/1). | 1.67 |
| 198 | Siltstone, fine-grained, olive-gray (5Y4/1). Fissile. | 0.5 |
| 197 | Siltstone, coarse-grained, olive-gray (5Y4/1). | 2.0 |
| 196 | Siltstone, coarse-grained, to sandstone, very fine grained, dark-yellowish-gray (5Y6/2). Massive, spheroidal weathering. | 1.67 |
| 195 | Siltstone, fine-grained, dusky-yellow (5Y5/4). Fissile. | 3.0 |
| 194 | Siltstone, coarse-grained, dark-yellowish-gray (5Y6/2). Massive, spheroidal weathering. | 0.75 |
| 193 | Siltstone, medium- to fine-grained, dark-yellowish-gray (5Y6/2). Fissile. | 3.83 |
| 192 | Siltstone, coarse-grained, yellowish-gray (5Y7/2). Massive, spheroidal weathering. | 0.83 |
| 191 | Siltstone, fine-grained, dusky-yellow (5Y5/4). Fissile. Coarse-grained siltstone to very fine grained sandstone bed in lower 0.33 ft., yellowish-gray (5Y7/2), massive. | 4.33 |
| 190 | Siltstone, fine-grained, light-grayish-olive (10Y5/2). Fissile. | 2.5 |
| 189 | Siltstone, coarse-grained, greenish-gray (5GY6/1). Massive, spheroidal weathering. | 2.0 |
| 188 | Siltstone, fine-grained, light-olive-gray (5Y6/1). Fissile. | 0.75 |
| 187 | Siltstone, medium-grained, dark-yellowish-gray (5Y6/2). Massive, spheroidal weathering. | 1.16 |
| 186 | Siltstone, fine-grained, medium-light-olive-gray (5Y5/1). Incipient fissility; fracture cleavage. | 3.83 |
| 185 | Siltstone, medium-grained, light-olive-gray (5Y5/2). Fractures into pencil fragments. | 2.25 |
| 184 | Siltstone, medium- to coarse-grained, light-olive-gray (5Y6/1). | 2.0 |
| 183 | Siltstone, medium- to coarse-grained, dark-grayish-yellow (5Y7/4). Massive. Fissile, fine-grained, light-olive-gray (5Y5/2) siltstone, 0.25 ft. thick, occurs 1.5 ft. below top of unit. | 5.50 |
| 182 | Sandstone, very fine grained, to siltstone, coarse-grained, dusky-yellow (5Y6/4). Massive. Spheroidal weathering. | 2.0 |
| 181 | Siltstone, fine-grained, dark-yellowish-gray (5Y6/2). Massive; pencil fractures. Basal 1.67 ft. is coarse-grained siltstone, dusky-yellow (5Y6/4). | 14.67 |
| 180 | Quartz conglomerate; granule-sized fragments. | 0.33 |
| 179 | Siltstone, fine-grained, dusky-yellow (5Y6/4). Fissile. | 1.5 |
| 178 | Siltstone, coarse-grained, to sandstone, very fine grained, dark-yellowish-gray (5Y6/2). Massive; spheroidal weathering. | 2.0 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 177 | Shale, dusky-yellow (5Y6/4). Fissile; pencil fractures. | 3.58 |
| 176 | Siltstone, coarse-grained, to sandstone, very fine grained, dusky-yellow (5Y6/4). A 0.16-ft.-thick bed of quartz conglomerate in a sandstone matrix occurs 1.33 ft. above base of unit. | 4.99 |
| 175D | Shale, dusky-yellow (5Y5/4). Fissile. | 1.0 |
| 175C | Siltstone, coarse-grained, light-olive-gray (5Y6/1). Massive. | 0.42 |
| 175B | Shale, dusky-yellow (5Y5/4). Fissile. | 0.33 |
| 175A | Siltstone, coarse-grained, light-olive-gray (5Y6/1). Massive. | 0.25 |
| 174 | Shale, olive-gray (5Y4/1). Fissile; pencil fractures. | 5.0 |
| 173 | Siltstone, medium-grained, medium-light-olive-gray (5Y5/1). Massive; spheroidal weathering. | 2.5 |
| 172 | Siltstone, medium-grained, dark-yellowish-gray (5Y6/2). | 1.25 |
| 171 | Siltstone, medium- to coarse-grained, dusky-yellow (5Y6/4). Fissile; pencil fractures. | 2.0 |
| 170 | Siltstone, coarse-grained, light-olive-gray (5Y6/1). Massive; spheroidal weathering. | 1.0 |
| 169 | Siltstone, medium-grained, dark-yellowish-gray (5Y6/2). Fissile, fractures into pencil shapes. | 3.0 |
| 168 | Sandstone, very fine grained, light-olive-gray (5Y6/1). Massive. | 3.67 |
| 167 | Shale, dark-yellowish-gray (5Y6/2). Fissile. | 0.58 |
| 166 | Siltstone, coarse-grained, dusky-yellow (5Y6/4). Massive; spheroidal weathering. | 2.0 |
| 165 | Shale, pale-yellowish-brown (10YR6/2). Fissile. | 1.0 |
| 164 | Siltstone, coarse-grained, dark-yellowish-gray (5Y6/2). Massive; spheroidal weathering. | 6.0 |
| 163 | Shale, dusky-yellow (5Y5/4). Fissile. | 1.0 |
| 162 | Siltstone, coarse-grained, to sandstone, very fine grained, dark-yellowish-gray (5Y6/2). Spheroidal weathering. | 0.75 |
| 161 | Siltstone, fine- to medium-grained, light-olive-gray (5Y5/2). Fractures into pencil shapes. | 11.5 |
| 160 | Siltstone, fine-grained, olive-gray (5Y4/1). | 4.67 |
| 159 | Siltstone, fine-grained, medium-dark-greenish-gray (5GY5/1). Massive. | 1.33 |
| 158 | Siltstone, medium-grained, light-olive-gray (5Y5/2). | 9.0 |
| 157 | Siltstone, medium- to coarse-grained, light-olive-gray (5Y6/1). Massive; spheroidal weathering. | 1.5 |
| 156 | Siltstone, fine-grained, medium-light-olive-gray (5Y4/2). | 2.33 |
| 155 | Siltstone, coarse-grained, dark-yellowish-gray (5Y6/2). Upper 0.67 ft. fractures to pencil shapes. | 6.67 |
| 154 | Siltstone, fine- to medium-grained, dark-yellowish-gray (5Y6/2). Fissile. | 0.83 |
| 153 | Siltstone, coarse-grained, dark-yellowish-gray (5Y6/2). | 8.5 |
| 152 | Siltstone, fine-grained, dusky-yellow (5Y6/4). Fractured. | 3.0 |
| 151 | Covered. | 3.0 |
| 150 | Siltstone, fine-grained, light-olive-gray (5Y5/2). Fractures to pencil shapes. | 2.0 |
| 149 | Covered. | 1.0 |
| 148 | Siltstone, medium-grained, dark-yellowish-gray (5Y6/2). Spheroidal weathering. | 0.33 |
| 147 | Siltstone, fine-grained, greenish-gray (5Y6/1). Fractured. | 2.0 |
| 146 | Siltstone, fine-grained, grayish-olive (10Y6/2). Covered. | 1.5 |
| 145 | Covered. | 2.0 |
| 144 | Siltstone, coarse-grained, light-olive-gray (5Y6/1). Load casts surrounded by fine-grained siltstone, grayish-olive (10Y4/2). | 8.25 |
| 143 | Siltstone, fine-grained, greenish-gray (5GY6/1). | 3.0 |
| 142 | Siltstone, medium-grained, greenish-gray (5GY6/1). | 0.75 |
| 141 | Covered. | 3.0 |
| 140 | Siltstone, coarse-grained, light-olive-gray (5Y6/1). Massive. Upper 1.5 ft. has spheroidal weathering. | 3.0 |
| 139 | Siltstone, medium-grained, greenish-gray (5GY6/1). | 2.75 |
| 138 | Siltstone, coarse-grained, light-olive-gray (5Y6/1). Massive; spheroidal weathering. | 3.33 |
| 137 | Siltstone, fine-grained, light-grayish-olive (10Y5/2). Incipient fissility. | 3.0 |
| 136 | Siltstone, coarse-grained, light-olive-gray (5Y6/1). | 1.67 |
| 135 | Siltstone, medium-grained. Upper half is greenish olive (10Y4/2) and fissile. Lower half is medium-dark-greenish gray (5GY6/1) and massive. | 1.0 |
| 134 | Siltstone, medium-grained, medium-light-bluish-gray (5B6/1). | 4.58 |
| 133 | Siltstone, medium- to coarse-grained, medium-light-olive-gray (5Y5/1). Massive. | 1.0 |
| 132 | Siltstone, fine-grained, medium-dark-greenish-gray (5GY5/1). Blocky fracture. | 2.5 |
| 131 | Siltstone, medium-grained, medium-light-gray (N6). | 0.75 |
| 130 | Siltstone, medium- to coarse-grained, medium-light-gray (N6). Load casts. | 4.16 |
| 129 | Siltstone, fine-grained, medium-light-bluish-gray (5B6/1). Massive. | 4.16 |
| 128 | Siltstone, medium- to coarse-grained, medium-light-bluish-gray (5B6/1). Massive. | 2.0 |
| 127 | Siltstone, fine-grained, medium-dark-greenish-gray (5GY6/1). | 1.5 |
| 126 | Siltstone, coarse-grained, light-olive-gray (5Y6/1). Massive; spheroidal weathering. | 1.0 |
| 125C | Siltstone, coarse-grained, light-bluish-gray (5B7/1). | 1.33 |
| 125B | Siltstone, fine-grained, dark-greenish-gray (5GY4/1). Fissile. | 0.5 |
| 125A | Siltstone, coarse-grained, light-bluish gray (5B7/1). | 1.16 |
| 124 | Sandstone, very fine grained, to siltstone, coarse-grained, medium-light-gray (N6). Massive. | 0.83 |
| 123 | Siltstone, fine- to medium-grained, medium-light-bluish-gray (5B6/1). Massive. | 2.0 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 122 | Sandstone, very fine grained, medium-gray (N5), massive, alternating with siltstone, fine-grained, dark-greenish-gray (5GY4/1), fissile. Eleven alternating 0.5-ft. beds of fissile siltstone and massive sandstone. | 5.5 |
| 121 | Siltstone, fine- to medium-grained, medium-light-olive-gray (5Y5/1). Massive; load casts. | 16.0 |
| 120 | Siltstone, medium-grained, medium-gray (N5). | 4.0 |
| 119 | Siltstone, medium- to coarse-grained, dark-yellowish-gray (5Y6/2). Fractures into pencil shapes in the lower 2 ft. | 5.0 |
| 118 | Sandstone, very fine grained, moderate-yellowish-brown (10YR5/4). | 6.0 |
| 117 | Siltstone, fine-grained, moderate-dusky-yellow (5Y5/4). Fractures into pencil shapes. | 2.0 |
| 116 | Siltstone, medium-grained, dark-yellowish-gray (5Y6/2). | 1.83 |
| 115 | Siltstone, medium- to fine-grained, moderate-dusky-yellow (5Y5/4). Fractures into pencil fragments. | 8.0 |
| 114 | Sandstone, very fine grained, to siltstone, coarse-grained, pale-yellowish-brown (10YR6/2). Massive. (End of third culvert.) | 0.75 |
| 113 | Siltstone, fine-grained, medium-light-olive-gray (5Y5/1). Incipient pencil-shaped fractures. | 8.5 |
| 112 | Sandstone, very fine grained, to siltstone, coarse-grained, light-olive-gray (5Y6/1). Massive. | 11.5 |
| 111 | Shale to siltstone, fine-grained, dark-greenish-gray (5G4/1). Upper 1 ft. has incipient fissility. | 3.16 |
| 110 | Siltstone, fine-grained, dark-greenish-gray (5GY4/1). Fracture cleavage. | 0.83 |
| 109 | Siltstone, medium-grained, medium-light-gray (N6). | 1.67 |
| 108 | Siltstone, fine-grained, medium-gray (N5). | 4.0 |
| 107 | Sandstone, very fine grained, to siltstone, coarse-grained, medium-light-gray (N6). Spheroidal weathering. | 0.67 |
| 106 | Siltstone, medium- to fine-grained, medium-dark-greenish-gray (5GY5/1). Blocky fracture. | 2.0 |
| 105 | Siltstone, medium-grained, medium-light-bluish-gray (5B6/1). | 0.75 |
| 104 | Siltstone, fine-grained, medium-gray (N5). Massive. | 2.5 |
| 103 | Siltstone, fine-grained, medium-dark-gray (N4). | 1.0 |
| 102 | Siltstone, fine- to medium-grained, medium-dark-greenish-gray (5G5/1) to medium-light-gray (N6). Base of unit marked by spheroidal forms. | 9.5 |
| 101 | Siltstone, medium-grained, medium-light-gray (N6), massive, interbedded with 8 units of siltstone, fine-grained, light-olive-gray (5Y5/2). Fissile. | 12.0 |
| 100 | Siltstone, fine-grained, medium-light-olive-gray (5Y5/1). Spheroidal forms in middle third. | 4.0 |
| 99 | Siltstone, medium- to coarse-grained, medium-light-gray (N6). Massive with spheroidal weathering. | 2.5 |
| 98 | Siltstone, fine-grained, medium-light-olive-gray (5Y4/2). | 0.91 |
| 97 | Siltstone, medium-grained, medium-light-olive-gray (5Y5/1). | 1.16 |
| 96 | Siltstone, medium- to fine-grained, light-bluish-gray (5B7/1). Massive. | 5.0 |
| 95 | Siltstone, medium-grained, medium-light-gray (N6). Massive; spheroidal weathering. | 1.83 |
| 94 | Siltstone, medium-grained, medium-dark-greenish-gray (5G5/1). Massive. | 4.0 |
| 93 | Siltstone, coarse-grained, medium-light-bluish-gray (5B6/1). Massive; spheroidal weathering. | 1.83 |
| 92C | Siltstone, fine- to medium-grained, medium-dark-greenish-gray (5GY5/1). | 0.92 |
| 92B | Siltstone, coarse-grained, medium-light-olive-gray (5Y5/1). | 0.25 |
| 92A | Siltstone, medium- to fine-grained, medium-dark-greenish-gray (5GY5/1). | 0.16 |
| 91 | Siltstone, coarse-grained, greenish-gray (5GY6/1). | 1.0 |
| 90 | Siltstone, coarse-grained, medium-light-olive-gray (5Y5/1). | 1.0 |
| 89 | Siltstone, medium-grained, medium-dark-greenish-gray (5GY5/1). | 1.33 |
| 88E | Siltstone, coarse-grained, to sandstone, very fine grained, medium-light-olive-gray (5Y5/1). | 0.5 |
| 88D | Siltstone, coarse-grained, to sandstone, very fine grained, medium-light-olive-gray (5Y5/1). Contains crinoid fragments. | 0.16 |
| 88C | Siltstone, coarse-grained, to sandstone, very fine grained, medium-light-olive-gray (5Y5/1). | 0.16 |
| 88B | Siltstone, coarse-grained, to sandstone, very fine grained, medium-light-olive-gray (5Y5/1). Contains crinoid fragments. | 0.16 |
| 88A | Siltstone, coarse-grained, to sandstone, very fine grained, medium-light-olive-gray (5Y5/1). | 0.33 |
| 87G | Siltstone; crinoid fragments; bed leached. | 0.16 |
| 87F | Siltstone. | 1.75 |
| 87E | Siltstone; crinoid fragments; bed leached. | 0.33 |
| 87D | Siltstone. | 1.58 |
| 87C | Siltstone; crinoid fragments; bed leached. | 0.42 |
| 87B | Siltstone. | 5.33 |
| 87A | Siltstone; crinoid fragments; bed leached. | 0.16 |
| 86F | Siltstone, coarse-grained, to sandstone, very fine grained, light-olive-gray (5Y6/1). | 0.5 |
| 86E | Siltstone, fine-grained, medium-light-olive-gray (5Y5/1). | 0.33 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 86D | Siltstone, medium- to coarse-grained, to sandstone, very fine grained, medium-light-olive-gray (5Y5/1). | 0.42 |
| 86C | Siltstone, fine-grained, medium-light-olive-gray (5Y5/1). | 0.25 |
| 86B | Siltstone, coarse-grained, to sandstone, very fine grained, light-olive-gray (5Y6/1). | 0.16 |
| 86A | Siltstone, fine-grained, medium-light-olive-gray (5Y5/1). | 0.25 |
| 85 | Sandstone, very fine grained, light-olive-gray (5Y6/1). Massive. | 1.25 |
| 84 | Alternating beds of shale, each 0.25 ft. thick, dusky-yellow (5Y5/4), and siltstone, coarse-grained, dark-yellowish-gray (5Y6/2), massive. | 7.75 |
| 83 | Sandstone, very fine grained, to siltstone, coarse-grained, medium-light-olive-gray (5Y5/1). Leached zone of crinoid imprints, 0.75 ft. thick, occurs 0.5 ft. above base. Load casts near base. | 5.58 |
| 82 | Siltstone, fine-grained, medium-light-olive-gray (5Y5/1). Incipient fissility and fracture cleavage. | 3.0 |
| 81 | Sandstone, very fine grained, to siltstone, coarse-grained, light-olive-gray (5Y6/1). | 0.83 |
| 80D | Siltstone, coarse-grained, greenish-gray (5GY6/1). | 0.67 |
| 80C | Siltstone, fine-grained, dark-greenish-gray (5GY4/1). | 0.8 |
| 80B | Siltstone, coarse-grained, light-olive-gray (5Y6/1). Crinoid imprints; bed leached. | 0.5 |
| 80A | Shale, grayish-olive (10Y4/2). Incipient fissility and fracture cleavage. | 3.08 |
| 79 | Sandstone, very fine grained, to siltstone, coarse-grained, light-olive-gray (5Y6/1). Massive with spheroidal weathering. | 2.0 |
| 78 | Shale and siltstone, coarse-grained, pale-olive (10Y6/2). Interbedded; incipient fissility. | 0.67 |
| 77 | Siltstone, coarse-grained, pale-orange-brown (10YR7/2). Massive. | 1.5 |
| 76B | Siltstone, medium-grained, medium-light-gray (N6). | 12.0 |
| 76A | Shale to siltstone, fine-grained, very dark greenish gray (10Y5/6). | 5.0 |
| 75C | Sandstone, very fine grained, to siltstone, coarse-grained, light-olive-gray (5Y6/1). Massive. | 3.5 |
| 75B | Siltstone, fine-grained, olive-gray (5Y4/1). Incipient fissility. | 2.33 |
| 75A | Siltstone, coarse-grained. Medium-olive-gray (5Y5/1). Massive. | 0.8 |
| 74 | Siltstone, fine-grained, grayish-olive (10Y4/2). Incipient fissility. | 0.67 |
| 73 | Sandstone, very fine grained, light-olive-gray (5Y6/1). Sandstone has interbedded leached zones containing crinoids. | 11.91 |
| 72B | Siltstone, medium-grained, greenish-gray (5GY6/1). Top at middle of second culvert. | 9.0 |
| 72A | Sandstone, very fine grained, to siltstone, coarse-grained, light-olive-gray (5Y6/1). | 3.0 |
| 71 | Shale, grayish-olive (10Y4/2). Incipient fissility. Fracture cleavage. | 2.5 |
| 70 | Siltstone, medium- to coarse-grained, medium-light-olive-gray (5Y5/1). Load casts surrounded by fine-grained siltstone, dark-grayish-olive (10Y3/2). | 19.0 |
| 69 | Siltstone, medium-grained, greenish-gray (5G6/1). Massive. | 3.5 |
| 68 | Siltstone, medium-grained, medium-greenish-gray (5GY5/1). | 8.0 |
| 67 | Siltstone, coarse-grained, dark-yellowish-gray (5Y6/2). Incipient fissility. Fracture cleavage. | 2.5 |
| 66 | Siltstone, coarse-grained, greenish-gray (5G6/1). Load casts surrounded by siltstone, greenish-gray (5GY6/1). | 12.0 |
| 65B | Siltstone, coarse-grained, light-olive-gray (5Y6/1). Incipient load cast surrounded by fine-grained siltstone. Rotated fossil horizon. | 13.5 |
| 65A | Siltstone, fine-grained, medium-light-olive-gray (5Y5/1). Incipient fissility. | 4.5 |
| 64B | Sandstone, very fine grained, to siltstone, coarse-grained, medium-dark-greenish-gray (5GY5/1). | 1.42 |
| 64A | Sandstone, very fine grained, to siltstone, coarse-grained, medium-dark-greenish-gray (5GY5/1). Massive. Fine- to medium-grained siltstone in top 0.25 ft., massive, leached, contains crinoids. | 15.08 |
| 63 | Siltstone, fine-grained, dark-greenish-gray (5GY4/1). Fissile; fracture cleavage. | 1.0 |
| 62 | Sandstone, very fine grained, to siltstone, coarse-grained, greenish-gray (5GY6/1) to medium-dark-greenish-gray (5GY5/1). Spheroidal weathering. Medium-grained siltstone (massive, 6 ft. thick) located 2 ft. above base of unit. | 12.0 |
| 61 | Siltstone, fine- to medium-grained, greenish-gray (5GY6/1) to medium-light-greenish-gray (5G7/1). Leached in 0.16-ft.-thick zone, 1.58 ft. below top. Crinoid fragments. | 4.29 |
| 60 | Siltstone, medium-grained, medium-dark-greenish-gray (5GY5/1). Massive. | 1.83 |
| 59 | Siltstone, fine-grained, grayish-olive (10Y4/2). Incipient fissility. | 0.91 |
| 58 | Siltstone, medium-grained, medium-light-gray (N6). Massive. Lower 3 in. is leached and has crinoid columnals. | 0.75 |
| 57 | Sandstone, very fine grained, to siltstone, coarse-grained, light-olive-gray (5Y6/1) to medium-light-gray (N6). Leached; has crinoid imprints 0.8 ft. above base. | 4.47 |
| 56 | Sandstone, very fine grained, to siltstone, coarse-grained, light-olive-gray (5Y6/1). Lower 4 in. leached. | 0.75 |
| 55 | Siltstone, coarse- and fine-grained. Fine-grained portion is medium-greenish gray (5G5/1). Coarse-grained portion is greenish gray (5G6/1). | 4.33 |
| 54 | Siltstone, coarse-grained, light-yellowish-gray (5Y6/2). | 0.75 |
| 53 | Siltstone, fine-grained, grayish-olive (10Y4/2). | 0.83 |
| 52 | Sandstone, very fine grained, olive-gray (5Y4/1). Leached in lower 1.25 ft.; crinoid columnals in lower 0.5 ft. | 1.83 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 51 | Shale, grayish-olive (10Y4/2). Fracture cleavage. | 1.0 |
| 50 | Sandstone, very fine grained, medium-light-gray (N6). | 3.33 |
| 49 | Shale, pale-grayish-olive (10Y5/2). Fissile. | 0.25 |
| 48 | Sandstone, very fine grained, to siltstone, coarse-grained, greenish-gray (5GY6/1). Massive. | 7.0 |
| 47 | Shale, light-grayish-olive (10Y5/2). Fissile, fractured. A 0.25-ft.-thick bed of very fine grained sandstone to coarse-grained siltstone, light-olive-gray (5Y5/2), massive, occurs 0.67 ft. above base. | 2.16 |
| 46 | Sandstone, very fine grained, and siltstone, coarse-grained, greenish-gray (5GY6/1). | 4.58 |
| 45 | Shale, dusky-yellow (5Y5/4). | 1.0 |
| 44B | Sandstone, very fine grained, dark-greenish-gray (5YR4/1). | 14.08 |
| 44A | Sandstone, very fine grained, light-olive-gray (5Y5/2). Partly covered. | 26.29 |
| 43 | Sandstone, very fine grained, dusky-yellow (5Y6/4), in upper 2 ft. Lower part is shale, light-olive-gray (5Y5/2), fissile. | 5.42 |
| 42 | Equally spaced, alternating beds of siltstone, coarse- and fine-grained, each 1.25 ft. thick. Fine-grained siltstone is light-grayish olive (10Y5/2). Coarse-grained siltstone is pale olive (10Y6/2). | 5.0 |
| 41 | Siltstone, fine-grained, medium-light-olive-gray (5Y4/2). | 2.67 |
| 40D | Siltstone, coarse-grained, medium-light-olive-gray (5Y4/2). Massive. | 0.58 |
| 40C | Siltstone, fine-grained, to shale, medium-light-olive-gray (5Y4/2). Incipient fissility; pencil fractures. | 0.33 |
| 40B | Siltstone, coarse-grained, medium-light-olive-gray (5Y4/2). Massive. | 0.67 |
| 40A | Siltstone, fine-grained, to shale, medium-light-olive-gray (5Y4/2). Fissile; pencil fractures. | 0.33 |
| 39 | Sandstone, very fine grained, to siltstone, coarse-grained, medium-light-olive-gray (5Y5/1). Massive. | 1.83 |
| 38 | Siltstone, fine-grained, olive-gray (5Y4/1). | 3.33 |
| 37 | Sandstone, very fine grained, medium-light-olive-gray (5Y5/1). Massive. | 1.0 |
| 36 | Siltstone, fine-grained, to shale, pale-olive (10Y6/2). Fissile. A 0.75-ft.-thick bed of very fine grained sandstone to coarse-grained siltstone, moderate-dusky-yellow (5Y5/4), occurs 0.5 ft. above base. Massive. | 4.0 |
| 35 | Sandstone, very fine grained, light-yellowish-gray (5Y6/2). Massive. A 0.67-ft.-thick leached bed containing crinoid columnals occurs 2.33 ft. above base. | 4.33 |
| 34 | Siltstone, fine-grained, to shale, dusky-yellow (5Y6/4). Fissile. Interbedded. | 2.0 |
| 33 | Sandstone, very fine grained, greenish-gray (5Y6/1). | 3.5 |
| 32 | Siltstone, fine-grained, to shale, dusky-yellow (5Y5/4). Fissile and fractured. Partly covered. | 24.45 |
| 31 | Sandstone, very fine grained, to siltstone, coarse-grained, dusky-yellow (5Y6/4). Massive. A 0.92-ft.-thick bed of fine-grained siltstone to shale, grayish-dusky-yellow (5Y7/4), fissile, occurs 0.13 ft. above base. | 3.97 |
| 30 | Sandstone, very fine grained, to siltstone, coarse-grained, dusky-yellow (5Y5/4). A conglomerate zone of angular and glassy quartz fragments up to 5 mm in diameter occurs 0.33 ft. above base. | 4.22 |
| 29 | Siltstone, fine-grained, dusky-yellow (5Y6/4). Fissile, fractured. Deeply weathered. | 6.45 |
| 28 | Sandstone, very fine grained, to siltstone, coarse-grained, greenish-gray (5Y6/1). | 4.5 |
| 27 | Siltstone, fine- to medium-grained, moderate-olive-brown (5Y4/4). Fissile and fractured. | 9.27 |
| 26 | Sandstone, very fine grained, medium-dark-greenish-gray (5GY5/1). Leached near top. | 11.0 |
| 25 | Shale, dusky-yellow (5Y5/4). Fissile and fractured. | 9.26 |
| 24 | Sandstone, very fine grained, dark-yellowish-gray (5Y6/2). | 6.76 |
| 23 | Sandstone, very fine grained, dark-yellowish-gray (5Y6/2). Massive. | 3.0 |
| 22 | Sandstone, very fine grained, dark-grayish-yellow (5Y7/4). Lower half very light gray (N8), contains plant imprints. Partly covered. | 8.45 |
| 21 | Sandstone, fine-grained, dark-yellowish-gray (5Y6/2). | 11.8 |
| 20 | Shale, dusky-yellow (5Y5/4). Fissile. Mainly covered. | 6.0 |
| 19 | Siltstone, fine- to medium-grained, grayish-olive (10Y4/2). Fissile and fractured. | 1.16 |
| 18* | Siltstone, coarse-grained, greenish-gray (5GY6/1). Massive. Base rests directly upon top of Walcksville Member. | 1.16 |
|  | Total | 963.15 |

* Original units 1-17 included in this member during field measurement are part of the underlying Walcksville Member.

## SECTION 12

## LONG RUN MEMBER OF CATSKILL FORMATION

Type section of the Long Run Member of Catskill Formation, located in part along U.S. Route 209 and in part in cuts of the former railroad just east of and below U.S.

Route 209 on the west bank of the Lehigh River (Figure 101). Cummings School at Packerton stands on a hill west of the roadcuts and railroad cuts. Base of section is 6,500 feet north of latitude 40°50′ and 1,500 feet west of longitude 75°42′30″. Section measured by J. D. Glaeser.

Units with C prefix were measured on U.S. Route 209 just north of Beaverdam Run. Units with D prefix were measured along railroad cuts just east of U.S. Route 209. Units D-83-77 were measured on U.S. Route 209. Units with E prefix were measured along railroad cuts just east of U.S. Route 209.

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| E-195 | Siltstone, fine-grained, grayish-red (5R4/2). | 0.67 |
| E-194 | Shale, dark-grayish-red (5R3/2). Massive. Incipient fissility. | 6.08 |
| E-193 | Shale, dark-grayish-red (5R3/2). Fissile. | 5.67 |
| E-192 | Siltstone, coarse-grained, to sandstone, very fine grained, red. Leached. Massive. | 8.96 |
| E-191 | Sandstone, very fine grained, to siltstone, coarse- to medium-grained, grayish-red (5R4/2). Incipient fissility. | 1.5 |
| E-190C | Siltstone, coarse-grained, brownish-gray (5YR4/1). | 3.33 |
| E-190B | Siltstone, coarse-grained, medium-light-brownish-gray (5YR5/1). | 8.0 |
| E-190A | Sandstone, very fine grained, greenish-gray (5GY6/1). No break in lithology, grades into B. | 1.67 |
| E-189 | Sandstone, very fine grained, platy to fissile, greenish-gray (5GY6/1). | 0.5 |
| E-188 | Sandstone, very fine grained, pale-olive (10Y6/2). | 2.41 |
| E-187 | Sandstone, medium- to coarse-grained, greenish-gray (5GY6/1). Blocky. | 10.0 |
| E-186 | Sandstone, fine- to medium-grained, medium-bluish-gray (5B5/1). Massive. | 6.33 |
| E-185 | Siltstone, medium-grained, medium-reddish-brown (10R4/4). Massive. | 3.0 |
| E-184 | Siltstone, fine- to medium-grained, grayish-red (10R4/2). Individual beds wedge out. | 3.0 |
| E-183 | Siltstone, medium-grained, grayish-red (10R4/2). Massive. | 1.67 |
| E-182 | Siltstone, medium-grained, grayish-red (10R4/2). | 2.5 |
| E-181 | Shale, grayish-red (5R4/2). Incipient fissility. | 3.0 |
| E-180 | Siltstone, medium-grained, grayish-red (10R4/2). | 2.0 |
| E-179 | Siltstone, fine- to medium-grained, grayish-red (5R4/2). | 10.0 |
| E-178 | Siltstone, coarse-grained, grayish-red (5R4/2). Massive. Leached at top. Basal 0.16 ft. is sandstone, very fine grained, moderate-brown (5YR4/4). | 1.66 |
| E-177 | Siltstone, fine- to medium-grained, dusky-red (5R3/4). Incipient fissility. | 1.33 |
| E-176 | Siltstone, coarse-grained, grayish-red (5R4/2). Massive. Leached in the lower 0.75 ft. | 4.16 |
| E-175 | Shale, dark-reddish-brown (10R3/4), interbedded with siltstone, coarse-grained to sandstone, very fine grained, grayish-red (5R4/2). Sandstone and siltstone massive; shale fissile. | 5.89 |
| E-174B | Sandstone, fine-grained, grayish-red (5R4/2) to greenish-gray (5YR6/1). | 11.0 |
| E-174A | Sandstone, medium-grained, greenish-gray (5GY6/1), grades into unit 174B. | 13.0 |
| E-173 | Covered. | 6.67 |
| E-172 | Sandstone, very fine grained, dark-greenish-gray (5GY4/1). Massive. | 5.0 |
| E-171 | Sandstone, very fine grained, medium-dark-greenish-gray (5GY5/1). | 7.0 |
| E-170 | Siltstone, coarse-grained, greenish-gray (5Y6/1). Incipient fissility. | 1.67 |
| E-169 | Sandstone, very fine grained, dark-greenish-gray (5G4/1). Basal 0.67 ft. leached, moderate-yellowish-brown (5YR5/4). Zone contains shale fragments, less than 4 mm, greenish-gray (5G6/1). | 7.0 |
| E-168 | Shale, medium-dark-greenish-gray (5GY5/1). | 0.25 |
| E-167 | Shale, dusky-red (5R3/4). Incipient fissility. | 18.6 |
| E-166 | Covered. | 2.0 |
| E-165 | Shale to siltstone, fine-grained, moderate-red (5R4/4). Incipient fissility. | 7.0 |
| E-164 | Siltstone, fine-grained, medium-reddish-brown (10R4/4). | 4.33 |
| E-163 | Siltstone, fine- to medium-grained, dusky-moderate-red (5R4/4). | 3.67 |
| E-162 | Siltstone, coarse-grained, grayish-red (5R4/2). | 9.33 |
| E-161 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). | 10.0 |
| E-160 | Siltstone, fine-grained, dark-grayish-red (5R3/2). Flaggy. | 3.58 |
| E-159 | Siltstone, coarse-grained, massive, grayish-red (5R4/2). Massive. | 0.75 |
| E-158 | Siltstone, coarse-grained, to sandstone, very fine grained, grayish-red (5R4/2). Massive. | 6.25 |
| E-157 | Siltstone and shale, fine-grained, fissile, grayish-red (10R4/2). | 0.67 |
| E-156 | Siltstone, coarse-grained, grayish-red (5R4/2). Massive. | 1.33 |
| E-155 | Siltstone, fine-grained, grayish-red (5R4/2). Platy. More compact than other fine sediments up to this unit. | 23.5 |
| E-154 | Siltstone, fine-grained, medium-dark-greenish-gray (5GY5/1). Incipient fissility. | 5.33 |
| E-153 | Siltstone, medium-grained, light-grayish-red (5R5/2). Upper 0.25 in. is fine-grained siltstone, mixed greenish-gray (5GY6/1) and grayish-red (5R4/2). | 3.03 |
| E-152 | Sandstone, fine-grained, medium-light- gray (N6). | 13.0 |
| E-151 | Covered. | 29.6 |
| E-150 | Sandstone, fine-grained, dusky-yellow (5Y5/4). | 25.0 |
| E-149 | Shale, medium-light-olive-gray (5Y5/1). Incipient fissility. | 5.33 |
| E-148 | Shale to siltstone, fine-grained, grayish-red (5R4/2). | 12.0 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| E-147C | Siltstone, fine- to medium-grained, medium-dark-greenish-gray (5G5/1). Break in color but not in bedding. | 2.0 |
| E-147B | Siltstone, coarse-grained, to sandstone, very fine grained, greenish-gray (5G6/1). | 2.5 |
| E-147A | Sandstone, very fine to fine-grained, greenish-gray (5G6/1). | 5.5 |
| E-146 | Covered. | 25.2 |
| E-145 | Sandstone, medium-grained, yellowish-gray (5Y7/2). | 11.0 |
| E-144 | Siltstone, fine-grained, grayish-red (5R4/2). Prominent fracture cleavage. | 4.16 |
| E-143B | Siltstone, coarse-grained, to sandstone, very fine grained, grayish-red (10R4/2). | 6.25 |
| E-143A | Sandstone, fine- to very fine grained, light-brownish-gray (5YR6/1). | 10.75 |
| E-142 | Sandstone, medium- to fine-grained, greenish-gray (5GY6/1). Massive. | 8.0 |
| E-141 | Siltstone, fine-grained, dark-greenish-gray (5GY4/1). | 13.0 |
| E-140 | Sandstone, very fine to fine-grained, medium-light-greenish-gray (5GY7/1). | 2.33 |
| E-139 | Siltstone, coarse-grained, to sandstone, very fine grained, greenish-gray (5G6/1). | 16.5 |
| E-138 | Siltstone, fine- to medium-grained, moderate-red (5R4/4). Fracture cleavage. | 14.0 |
| E-137 | Siltstone, fine-grained, grayish-red (10R4/2). | 5.83 |
| E-136 | Covered. | 8.15 |
| E-135 | Siltstone, fine- to medium-grained, grayish-red (10R4/2). Fracture cleavage. | 26.0 |
| E-134 | Siltstone, coarse-grained, light-grayish-red (5R5/2). | 3.33 |
| E-133 | Siltstone, coarse-grained, to sandstone, very fine grained, greenish-gray (5GY6/1). | 4.16 |
| E-132 | Shale, medium-dark-greenish-gray (5GY5/1). Fissile. | 1.5 |
| E-131 | Shale to siltstone, fine-grained, grayish-red (5R4/2). | 17.0 |
| E-130 | Sandstone, fine- to medium-grained, medium-dark-greenish-gray (5G5/1). | 22.0 |
| E-129 | Sandstone, very fine to fine-grained, greenish-gray (5G6/1). Massive. | 9.0 |
| E-128 | Siltstone, coarse-grained, greenish-gray (5GY6/1). Incipient fissility. | 0.25 |
| E-127 | Sandstone, very fine to fine-grained, greenish-gray (5GY6/1). Massive. | 12.0 |
| E-126 | Sandstone, very fine grained, greenish-gray (5GY6/1). | 3.0 |
| E-125 | Shale, medium-dark-greenish-gray (5GY5/1). | 1.0 |
| E-124 | Siltstone, fine-grained, grayish-red (5R4/2). Incipient fracture cleavage. | 1.67 |
| E-123 | Siltstone, medium-grained, grayish-red (5R4/2). | 6.0 |
| E-122 | Siltstone, coarse-grained, grayish-red (5R4/2). Massive. | 1.83 |
| E-121 | Siltstone, coarse-grained, light-grayish-red (5R5/2). Massive. | 11.5 |
| E-120 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Incipient fracture cleavage. | 12.0 |
| E-119 | Siltstone, medium-grained, grayish-red (10R4/2). Massive. | 0.75 |
| E-118 | Shale, dusky-moderate-red (5R4/4). Incipient fracture cleavage. | 1.16 |
| E-117 | Siltstone, medium-grained, light-grayish-red (5R5/2). Massive. | 0.5 |
| E-116 | Shale, grayish-red (5R4/2). Fracture cleavage. | 9.0 |
| E-115 | Siltstone, fine-grained, grayish-red (5R4/2). Massive. | 3.6 |
| E-114 | Siltstone, fine-grained, dusky-red (5R3/4). Fracture cleavage. | 74.3 |
| E-113 | Covered. | 141.0 |
| E-112 | Siltstone, fine-grained, dusky-red (5R3/4). Fracture cleavage. | 34.0 |
| E-111 | Siltstone, fine-grained, moderate-red (5R4/4). Massive. | 1.83 |
| E-110 | Siltstone, fine-grained, grayish-red (10R4/2). Incipient fissility. | 1.0 |
| E-109 | Covered. | 8.0 |
| E-108 | Siltstone, fine-grained, grayish-red (5R4/2). Fracture cleavage. | 10.0 |
| E-107 | Siltstone, medium-grained, light-grayish-olive (10Y5/2). | 8.0 |
| E-106 | Sandstone, fine-grained, greenish-gray (5G6/1). | 6.5 |
| E-105 | Covered. | 12.0 |
| E-104 | Sandstone, very fine grained to fine-grained, greenish-gray (5GY6/1). | 18.0 |
| E-103 | Covered. | 12.0 |
| E-102 | Siltstone, fine-grained, grayish-red (5R4/2). | 4.0 |
| E-101 | Shale, moderate-red (5R4/4). Incipient fissility. | 1.33 |
| E-100 | Siltstone, fine-grained, grayish-red (5R4/2). | 2.5 |
| E-99 | Siltstone, fine- to medium-grained, grayish-red (5R4/2). Fissile. | 6.0 |
| E-98 | Sandstone, medium- to fine- to very fine grained, graded, pale-olive (10Y6/2). Upper 2.5 ft. is medium-light-brownish gray (5YR5/1). | 9.0 |
| E-97 | Shale, greenish-gray (5G6/1). Platy and fissile. | 5.0 |
| E-96 | Sandstone, fine-grained, greenish-gray (5GY6/1). | 1.33 |
| E-95 | Shale to siltstone, fine-grained, grayish-red (5R4/2). | 26.0 |
| E-94 | Siltstone, fine- to medium-grained, grayish-red (5R4/2). Fissile. | 3.5 |
| E-93 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Prominent fracture cleavage. | 11.0 |
| E-92 | Siltstone, coarse-grained, to sandstone, very fine grained, dark-reddish-brown (10R3/4). | 5.0 |
| E-91 | Shale, dark-reddish-brown (10R3/4). | 3.0 |
| E-90 | Covered. | 14.2 |
| E-89 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). | 10.0 |
| E-88 | Siltstone, fine- to medium-grained, light-grayish-red (5R5/2). | 2.83 |
| E-87 | Siltstone, medium-grained, dusky-moderate-red (5R4/4). | 13.0 |
| E-86 | Siltstone, medium-grained, grayish-red (5R4/2). Lower 0.67 ft. is very fine grained sandstone, grayish-red (10R4/2). | 5.16 |
| E-85 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Fracture cleavage. | 4.41 |
| E-84 | Sandstone, fine-grained, light-grayish-red (5R5/2). | 5.0 |
| E-83 | Siltstone, fine-grained, grayish-red (10R4/2). | 2.33 |
| E-82 | Shale, dark-reddish-brown (10R3/4). Fissile. | 2.5 |
| E-81 | Sandstone, fine-grained, light-grayish-red (5R5/2). | 11.0 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| E-80 | Sandstone, fine- to medium-grained, medium-light-greenish-gray (5GY7/1). Color transition without bedding break up into unit E-81. | 9.5 |
| E-79 | Siltstone, fine-grained, grayish-red (10R4/2). Fissile and fracture cleavage. | 3.0 |
| E-78 | Siltstone, fine-grained, dusky-red (5R3/4). Blocky. | 3.16 |
| E-77 | Siltstone, fine-grained, grayish-red (5R4/2). | 1.67 |
| E-76 | Siltstone, fine-grained, grayish-red (5R4/2). Massive. | 0.58 |
| E-75 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Lower 2 ft. leached. | 16.0 |
| E-74 | Siltstone, medium-grained, dusky-moderate-red (5R4/4). | 3.0 |
| E-73 | Siltstone, fine- to medium-grained, dusky-moderate-red (5R4/4). | 4.83 |
| E-72 | Sandstone, fine-grained, grayish-red (5R4/2). | 3.16 |
| E-71 | Siltstone, fine-grained, dusky-moderate-red (5R4/4) and pale-olive (10Y6/2). Color varies along bedding. | 0.33 |
| E-70 | Siltstone, coarse-grained, dusky-moderate-red (5R4/4). | 0.83 |
| E-69 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Incipient fracture cleavage. | 3.33 |
| E-68 | Sandstone, very fine grained, grayish-red (5R4/2). | 1.75 |
| E-67 | Siltstone, fine- to medium-grained, grayish-red (5R4/2). Incipient fracture cleavage. | 3.58 |
| E-66 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). | 1.0 |
| E-65 | Shale to siltstone, fine-grained, dusky-moderate-red (5R4/4). Fracture cleavage; fissile. | 2.0 |
| E-64 | Siltstone, medium-grained, grayish-red (5R4/2). | 2.5 |
| E-63 | Shale, dusky-red (5R3/4). | 0.5 |
| E-62 | Siltstone, fine- to medium-grained, grayish-red (5R4/2). Massive. | 1.0 |
| E-61 | Shale to siltstone, fine-grained, dusky-moderate-red (5R4/4). | 6.67 |
| E-60 | Shale, dark-reddish-brown (10R3/4). Fracture cleavage. | 6.33 |
| E-59 | Siltstone, fine- to medium-grained, grayish-red (5R4/2). | 1.67 |
| E-58 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Fracture cleavage. | 2.0 |
| E-57 | Shale to siltstone, fine-grained, dusky-moderate-red (5R4/4). | 0.67 |
| E-56 | Shale to siltstone, fine-grained, dusky-moderate-red (5R4/4). Fracture cleavage. | 3.16 |
| E-55 | Siltstone, fine- to medium-grained, grayish-red (5R4/2). | 6.0 |
| E-54 | Siltstone, coarse-grained, to sandstone, very fine grained, grayish-red (5R4/2). | 2.33 |
| E-53 | Siltstone, fine-grained, grayish-red (5R4/2). Prominent fracture cleavage. | 5.0 |
| E-52B | Siltstone, fine- to medium-grained, moderate-red (5R5/4). | 4.83 |
| E-52A | Sandstone, very fine grained, grayish-red (5R4/2). | 1.33 |
| E-51 | Siltstone, fine-grained, light-olive-gray (5Y6/1) in the upper half and grayish-red (5R4/2) in the lower half. | 1.33 |
| E-50 | Siltstone, fine-grained, grayish-red (10R4/2). Prominent fracture cleavage. | 0.58 |
| E-49 | Siltstone, medium-grained, grayish-red (5R4/2). Blocky. | 1.33 |
| E-48 | Siltstone, fine- to medium-grained, grayish-red (5R4/2). | 2.0 |
| E-47 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Upper 0.75 ft. is leached. | 2.67 |
| E-46 | Siltstone, medium-grained, grayish-red (5R4/2). | 8.0 |
| E-45 | Siltstone, fine-grained, grayish-red (10R4/2). Fracture cleavage. | 20.0 |
| E-44 | Siltstone, coarse-grained, to sandstone, very fine grained, grayish-red (5R4/2). | 5.83 |
| E-43 | Siltstone, fine-grained, grayish-red (5R4/2). Incipient fracture cleavage. | 7.33 |
| E-42 | Siltstone, coarse-grained, to sandstone, very fine grained, grayish-red (5R4/2). | 0.75 |
| E-41 | Siltstone, fine- to medium-grained, grayish-red (5R4/2). | 9.0 |
| E-40 | Siltstone, fine- to medium-grained, grayish-red (5R4/2). | 1.67 |
| E-39 | Siltstone, fine- to medium-grained, grayish-red (5R4/2). | 3.0 |
| E-38 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Prominent fracture cleavage. | 1.33 |
| E-37 | Siltstone, fine-grained, grayish-red (5R4/2). | 4.83 |
| E-36 | Siltstone, fine-grained, grayish-red (5R4/2). Prominent fracture cleavage. | 11.0 |
| E-35 | Siltstone, coarse-grained, to sandstone, very fine grained, grayish-red (5R4/2). Siliceous cement. Massive. | 5.33 |
| E-34 | Siltstone, medium-grained, grayish-red (10R4/2). | 1.58 |
| E-33 | Siltstone, medium-grained, to sandstone, very fine grained, grayish-red (5R4/2). Massive. | 1.26 |
| E-32 | Siltstone, fine- to medium-grained, grayish-red (10R4/2). Fracture cleavage. | 4.0 |
| E-31 | Sandstone, very fine grained, light-grayish-red (5R5/2). | 0.67 |
| E-30 | Siltstone, fine- to medium-grained, pale-red (5R6/2) and grayish-red (5R4/2). Colors interbedded. | 2.5 |
| E-29 | Sandstone, fine-grained, greenish-gray (5GY6/1). | 3.0 |
| E-28 | Siltstone, fine- to medium-grained, light-olive (10Y5/2). Fissile. | 0.41 |
| E-27 | Sandstone, fine-grained, medium-light-olive-gray (5Y5/1). Massive. | 0.75 |
| E-26 | Siltstone, fine-grained, medium-light-greenish-gray (5GY7/1). Incipient fissility. | 2.5 |
| E-25 | Sandstone, fine-grained, greenish-gray (5Y6/1). Massive. | 3.67 |
| E-24 | Siltstone, fine-grained, greenish-gray (5GY6/1). Fissile. | 0.67 |
| E-23 | Sandstone, fine- to medium-grained, greenish-gray (5GY6/1). | 13.5 |
| E-22 | Shale, light-olive (10Y5/2). Prominent fissility. | 0.5 |
| E-21 | Shale to siltstone, fine-grained, grayish-red (10R4/2). Prominent fracture cleavage. | 2.0 |
| E-20 | Siltstone, medium-grained, grayish-red (5R4/2). | 1.0 |
| E-19 | Siltstone, fine-grained, grayish-red (5R4/2). | 23.0 |
| E-18 | Siltstone, medium-grained, grayish-red (5R4/2). | 3.58 |
| E-17 | Sandstone, very fine grained, to siltstone, coarse-grained, greenish-yellow (10Y7/2). Graded bed. | 8.41 |
| E-16 | Shale, pale-olive (10Y6/2). Prominent fracture cleavage. | 1.67 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| E-15 | Siltstone, fine-grained, greenish-gray (5GY6/1). | 1.16 |
| E-14 | Siltstone, medium-grained, dusky-moderate-red (5R4/4). Prominent fracture cleavage. | 5.0 |
| E-13 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2). | 2.83 |
| E-12 | Shale to siltstone, medium-grained, grayish-red (5R4/2). Lower 1.75 ft. fissile. Upper 6 ft. fracture cleavage. | 8.0 |
| E-11 | Siltstone, coarse-grained, grayish-red (5R4/2). Blocky. | 7.5 |
| E-10 | Siltstone, medium-grained, light-grayish-olive (10Y5/2). Flaggy to fissile. | 2.16 |
| E-9 | Siltstone, coarse-grained, to sandstone, very fine grained, dark-greenish-gray (5GY4/1). | 1.16 |
| E-8 | Siltstone, medium-grained, pale-olive (10Y6/2). Fracture cleavage. | 2.83 |
| E-7 | Siltstone, fine-grained, grayish-red (10R4/2). | 2.0 |
| E-6 | Siltstone, fine-grained, moderate-greenish-yellow (10Y6/4). Incipient fissility. | 4.5 |
| E-5 | Siltstone, fine-grained, grayish-red (5R4/2). Incipient fissility. | 6.33 |
| E-4 | Siltstone, fine-grained, medium-dark-greenish-gray (5GY5/1). | 2.5 |
| E-3 | Siltstone, coarse-grained, dark-yellowish-gray (5Y6/2). | 4.0 |
| E-2 | Sandstone, very fine grained, to siltstone, coarse-grained, pale-olive (10Y6/2). | 5.25 |
| E-1 | Sandstone, very fine grained, dark-yellowish-gray (5Y6/2). | 4.25 |
| D-83 | Covered. | 3.0 |
| D-82 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2). Partly exposed. | 35.7 |
| D-81 | Sandstone, very fine grained, to siltstone, coarse-grained, gray to green. Flaggy to massive. | 22.1 |
| D-80 | Sandstone, very fine grained, to siltstone, coarse-grained, red. | 10.8 |
| D-79 | Sandstone, gray-green. | 8.1 |
| D-78 | Siltstone, coarse- to medium-grained, red. | 40.8 |
| D-77 | Sandstone, very fine grained, to siltstone, medium- and coarse-grained, red. | 63.9 |
| D-76 | Siltstone, medium- to fine-grained, grayish-red (5R4/2). | 7.5 |
| D-75 | Sandstone, very fine grained, to siltstone, coarse-grained, light-grayish-red (5R5/2). | 7.5 |
| D-74 | Siltstone, medium- to fine-grained, dusky-moderate-red (5R4/4). | 5.0 |
| D-73 | Siltstone, medium-grained, grayish-red (5R4/2). | 11.0 |
| D-72 | Sandstone, fine- to very fine grained, grayish-red (5R4/2). Dominantly fine in upper half. | 15.5 |
| D-71 | Sandstone, fine- to very fine grained, dark-yellowish-gray (5Y6/2). Massive. | 1.91 |
| D-70 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Upper 0.25 in. is shale, medium-light-greenish-gray (5GY7/1). Prominent fissility. | 12.5 |
| D-69 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Fracture cleavage. | 1.58 |
| D-68 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). | 10.0 |
| D-67 | Siltstone, fine-grained, medium-reddish-brown (10R4/4). Fracture cleavage. | 11.0 |
| D-66 | Siltstone, medium-grained, grayish-red (5R4/2). | 4.25 |
| D-65 | Shale, grayish-red (5R4/2). Fissile. | 3.58 |
| D-64 | Siltstone, fine-grained, grayish-red (5R4/2). Incipient fracture cleavage. | 18.5 |
| D-63 | Sandstone, very fine grained, grayish-red (5R4/2). | 17.5 |
| D-62 | Siltstone, medium- to fine-grained, dusky-moderate-red (5R4/4). Prominent fracture cleavage. | 5.83 |
| D-61 | Siltstone, medium-grained, grayish-red (5R4/2). | 6.5 |
| D-60 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Prominent fracture cleavage. | 15.5 |
| D-59 | Siltstone, medium-grained, light-grayish-red (5R5/2). Massive. | 6.58 |
| D-58 | Shale, dusky-moderate-red (5R4/4). Prominent fracture cleavage. | 7.0 |
| D-57 | Siltstone, medium-grained, light-grayish-red (5R5/2). Massive. | 3.33 |
| D-56 | Siltstone, fine-grained, to shale, moderate-red (5R5/4). | 8.0 |
| D-55 | Siltstone, fine-grained, grayish-red (5R4/2). | 4.0 |
| D-54 | Siltstone, medium- to fine-grained, to shale, grading upward, grayish-red (5R4/2). Increasing fissility upward; fracture cleavage more apparent upward. | 8.5 |
| D-53 | Sandstone, very fine grained, and siltstone, coarse-grained, grayish-red (5R4/2). | 2.83 |
| D-52 | Sandstone, fine- to very fine grained, medium-light-olive-gray (5Y5/1). Massive. | 3.0 |
| D-51 | Shale, dusky-moderate-red (5R4/4); greenish gray (5GY6/1) in upper half. Fracture cleavage. | 1.67 |
| D-50 | Siltstone, fine-grained, grayish-red (5R4/2). | 1.25 |
| D-49 | Siltstone, fine-grained, dusky-red (5R3/4). | 3.0 |
| D-48 | Siltstone, medium-grained, grayish-red (5R4/2). | 12.0 |
| D-47 | Shale, greenish-gray (5GY6/1); light-brownish gray (5YR6/1) in upper half. Prominent fracture cleavage. | 0.83 |
| D-46 | Siltstone, coarse-grained, greenish-gray (5G6/1). | 1.25 |
| D-45 | Shale, greenish-gray (5GY6/1). Fissile; fracture cleavage. | 0.75 |
| D-44 | Siltstone, coarse-grained, dark-grayish-red (5R3/2). | 3.0 |
| D-43 | Sandstone, very fine grained, greenish-gray (5GY6/1). | 4.5 |
| D-42 | Pebble conglomerate. Matrix is greenish-gray (5G6/1) calcareous mud. Rounded dolomite clasts, dusky-yellowish-brown (5YR2/2). | 5.83 |
| D-41 | Shale, greenish-gray (5G6/1). Incipient fracture cleavage. | 0.75 |
| D-40 | Siltstone, medium- to fine-grained, grayish-red (5R4/2). Massive; conchoidal fracture. Upper 1.0 foot is shale. Incipient fracture cleavage. | 11.0 |
| D-39 | Siltstone, fine-grained, to shale, grayish-red (5R4/2). Incipient fissility. | 5.67 |
| D-38 | Siltstone, medium-grained, brownish-gray (5YR4/1). | 12.0 |
| D-37 | Covered. | 3.0 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| D-36 | Siltstone, medium-grained. Alternates in lower 9 in. between grayish-red (5R4/2) and light-olive-gray (5Y6/1). | 3.75 |
| D-35 | Sandstone, very fine grained, greenish-gray (5G6/1). Lower 3 ft. is massive. | 7.5 |
| D-34 | Sandstone, very fine grained, medium-dark-greenish-gray (5GY5/1). | 2.67 |
| D-33 | Shale, pale-grayish-olive (10Y5/2). Prominent fracture cleavage. | 0.25 |
| D-32 | Sandstone, very fine-grained, greenish-gray (5GY6/1). Massive. | 1.16 |
| D-31 | Siltstone, fine-grained, to shale, greenish-gray (5GY6/1). Prominent fracture cleavage. | 0.33 |
| D-30 | Sandstone, very fine grained, greenish-gray (5GY6/1). Massive. | 1.58 |
| D-29 | Siltstone, fine-grained, to shale, greenish-gray (5GY6/1). | 0.67 |
| D-28 | Siltstone, fine-grained, to shale, light-olive-gray (5Y5/2). Incipient fracture cleavage. | 3.33 |
| D-27 | Siltstone, fine-grained, grayish-red (5R4/2). | 2.25 |
| D-26 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Incipient fissility. | 1.33 |
| D-25 | Siltstone, medium-grained, dusky-moderate-red (5R4/4). | 1.0 |
| D-24 | Siltstone, fine-grained, to shale, dusky-moderate-red (5R4/4). Fracture cleavage. | 8.0 |
| D-23 | Siltstone, medium-grained, grayish-red (5R4/2). Massive. | 0.67 |
| D-22 | Siltstone, medium-grained, moderate-red (5R4/6). Fracture cleavage developed in scattered parts of bed. | 3.67 |
| D-21 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Fracture cleavage. Lower 9 in. leached. | 4.5 |
| D-20 | Siltstone, medium-grained, grayish-red (5R4/2). | 4.33 |
| D-19 | Siltstone, fine-grained, to shale, dusky-moderate-red (5R4/4). Upper 0.16 ft. leached. | 2.0 |
| D-18 | Siltstone, medium- to fine-grained, dusky-moderate-red (5R4/4). Weathers into concretionary forms. | 2.0 |
| D-17 | Siltstone, fine-grained, grayish-red (5R4/2). | 25.5 |
| D-16 | Siltstone, coarse-grained, grayish-red (5R4/2). | 2.67 |
| C-119B | Siltstone, medium-grained, grayish-red (5R4/2). | 2.00 |
| C-119A | Sandstone, very fine grained, medium-light-brownish-gray (5YR5/1). | 4.83 |
| C-118 | Siltstone, coarse-grained, grayish-red (5R4/2) and light-olive-gray (5Y6/1) (color mixed). | 0.67 |
| C-117 | Siltstone, coarse-grained, medium-light-greenish-gray (5G7/1). | 1.5 |
| C-116 | Siltstone, fine-grained, light-olive-gray (5G6/1). Fracture cleavage. | 1.83 |
| C-115 | Siltstone, fine-grained, grayish-red (5R4/2). Fissile. | 4.0 |
| C-114 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2). | 2.0 |
| C-113 | Siltstone, medium-grained, grayish-red (5R4/2). Fissile. | 8.0 |
| C-112 | Siltstone, medium-grained, pale-grayish-red (5R5/2). | 0.83 |
| C-111 | Shale, dusky-moderate-red (5R4/4). Fissile. | 1.33 |
| C-110 | Siltstone, medium-grained, grayish-red (5R4/2). | 0.75 |
| C-109 | Shale to siltstone, very fine grained, dusky-moderate-red (5R4/4). Fissile. | 5.67 |
| C-108 | Covered. | 3.58 |
| C-107 | Siltstone, fine-grained, grayish-red (5R4/2). | 7.0 |
| C-106 | Siltstone, fine-grained, grayish-red (5R4/2). Fissile; fracture cleavage. | 7.5 |
| C-105 | Siltstone, medium-grained, grayish-red (10R4/2). Massive. | 0.5 |
| C-104 | Shale, dusky-moderate-red (5R4/4). Fissile. | 4.0 |
| C-103 | Covered. | 19.0 |
| C-102 | Shale to siltstone, very fine grained, dusky-moderate-red (5R4/4). Fissile; fracture cleavage. | 0.75 |
| C-101 | Siltstone, fine-grained, grayish-red (5R4/2). Massive. | 0.83 |
| C-100 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Fissile; fracture cleavage. | 4.58 |
| C-99 | Siltstone, coarse- to medium-grained, grayish-red (5R4/2). | 5.67 |
| C-98 | Shale to siltstone, fine-grained, grayish-red (5R4/2). | 4.0 |
| C-97 | Covered. | 2.91 |
| C-96 | Siltstone, medium-grained, grayish-red (5R4/2). | 2.58 |
| C-95 | Siltstone, medium-grained, pale-red (5R6/2). | 0.25 |
| C-94 | Siltstone, coarse-grained, greenish-gray (5GY6/1). Upper 0.33 ft. contains shale fragments (rounded to subrounded), moderate-pink (5R7/4), in a matrix of coarse siltstone, pale-reddish-brown (10R5/4). | 0.49 |
| C-93 | Siltstone, fine-grained, greenish-gray (5GY6/1). Incipient fissility. | 2.0 |
| C-92 | Sandstone, fine- to very fine grained, light-olive-gray (5G6/1). Massive. | 0.33 |
| C-91 | Siltstone, medium-grained, pale-greenish-olive (10Y7/2). Fissile. | 0.75 |
| C-90 | Sandstone, very fine grained, to siltstone, coarse-grained, light-olive-gray (5Y6/1). Massive. | 0.83 |
| C-89 | Siltstone, fine-grained, yellowish-gray (5Y7/2). | 0.58 |
| C-88 | Sandstone, very fine grained, to siltstone, coarse-grained, light-olive-gray (5Y6/1). Massive. | 0.5 |
| C-87 | Shale, greenish-gray (5G6/1). Fissile. | 2.16 |
| C-86 | Siltstone, medium- to coarse-grained, greenish-gray (5GY6/1). | 1.0 |
| C-85 | Siltstone, fine-grained, grayish-red (5R4/2) dominant with minor light-olive-gray (5Y5/2). | 0.75 |
| C-84 | Shale to siltstone, fine-grained, dark-reddish-brown (10R3/4). | 3.33 |
| C-83 | Siltstone, medium-grained, grayish-red (5R5/2). Massive. | 0.5 |
| C-82 | Siltstone, fine-grained, grayish-red (5R4/2). Prominent fracture cleavage. | 2.67 |
| C-81 | Siltstone, medium-grained, pale-grayish-red (10R5/2). Massive. | 1.25 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| C-80 | Shale, dusky-moderate-red (5R4/4). Middle of unit is siltstone, coarse-grained, 0.16 ft. thick, massive. At base of bed is a painted sign "4/81." | 1.32 |
| C-79 | Siltstone, coarse-grained, grayish-red (5R4/2). | 1.33 |
| C-78 | Shale, grayish-red (10R4/2). Fissile. | 0.75 |
| C-77 | Siltstone, coarse-grained, pinkish-brownish-gray (5YR7/1). | 1.58 |
| C-76 | Sandstone, very fine to fine-grained, pale-olive (10Y6/2). | 12.0 |
| C-75 | Shale in top 0.75 ft., light-grayish-olive (10Y5/2); lower 1.25 ft. is siltstone, fine-grained, greenish-gray (5GY6/1). | 2.0 |
| C-74D | Shale, pale-grayish-yellow (10Y5/2), with minor red. | 1.67 |
| C-74C | Shale to siltstone, fine-grained, greenish-gray (5GY6/1) and grayish-red (5R4/2), in equal amounts. | 0.58 |
| C-74B | Shale to siltstone, fine-grained, greenish-gray (5GY6/1) (dominant) and grayish-red (5R4/2) (minor). | 0.75 |
| C-74A | Shale to siltstone, very fine grained, grayish-red (5R4/2) (dominant) and greenish-gray (5GY6/1) (minor). | 1.33 |
| C-73 | Shale, grayish-red (5R4/2). | 0.75 |
| C-72 | Siltstone, fine-grained, grayish-red (5R4/2). | 1.5 |
| C-71 | Siltstone, coarse- to medium-grained, pale-olive (10Y6/2). Color transition upward in top 1 in. | 1.16 |
| C-70 | Siltstone, fine- to medium-grained, dark-grayish-red (5R3/2). | 8.41 |
| C-69 | Siltstone, fine-grained, light-grayish-olive (10Y5/2), incipient fissility. | 6.5 |
| C-68 | Sandstone, very fine grained, pale-olive (10Y6/2). Massive. | 13.5 |
| C-67 | Shale, light-yellow-olive (10Y5/4). Fissile. | 0.41 |
| C-66 | Sandstone, very fine grained, pale-grayish-olive (10Y5/2). | 0.41 |
| C-65 | Siltstone, medium-grained, pale-olive (10Y6/2). | 3.41 |
| C-64 | Siltstone, medium- to coarse-grained, pale-grayish-olive (10Y5/2). | 1.75 |
| C-63 | Alternating beds of sandstone, very fine grained, light-olive-gray (5Y6/1) (starting at base), and shale, medium-light-brownish-gray (5YR5/1). Fissile. Eight alternations. | 1.36 |
| C-62 | Shale, grayish-red (10R4/2). | 1.75 |
| C-61 | Shale, dusky-red (5R3/4). Fissile. | 2.25 |
| C-60 | Shale, grayish-red (5R4/2). | 11.5 |
| C-59 | Shale, grayish-red (5R4/2). Fracture cleavage. | 6.0 |
| C-58 | Shale, grayish-red (5R4/2). Incipient fracture cleavage. | 2.67 |
| C-57 | Siltstone, coarse-grained, grayish-red (5R4/2). | 2.16 |
| C-56 | Siltstone, fine-grained, grayish-red (5R4/2). Fracture cleavage. | 2.0 |
| C-55 | Siltstone, coarse-grained, light-grayish-red (5R5/2). Massive. | 0.67 |
| C-54 | Sandstone, very fine grained, medium-light-brownish-gray (5YR5/1). | 4.0 |
| C-53D | Siltstone, light-olive-gray (5Y5/2). | 2.0 |
| C-53C | Shale, pale-grayish-olive (10Y5/2). Prominent fracture cleavage. | 2.33 |
| C-53B | Sandstone, very fine grained, to siltstone, coarse-grained, grayish-red (5R4/2). | 0.5 |
| C-53A | Siltstone, coarse-grained, pale-grayish-olive (10Y5/2). | 4.0 |
| C-52 | Shale, pale-olive (10Y6/2). Fracture cleavage. | 1.0 |
| C-51 | Siltstone, coarse-grained, grayish-red (5R4/2). Fracture cleavage. | 4.33 |
| C-50 | Siltstone, coarse-grained, to sandstone, very fine grained, grayish-red (5R4/2). Massive (this bed at intersection sign). | 8.0 |
| C-49 | Siltstone, coarse-grained, grayish-red (5R4/2). | 1.5 |
| C-48 | Quartz-shale conglomerate (2-4-mm clasts) with gray-green shale chips in lower 0.8 ft. Remainder of bed is siltstone, coarse-grained, to sandstone, very fine grained, dark-yellowish-gray (5Y6/2). | 6.0 |
| C-47 | Shale to siltstone, fine-grained, pale-olive (10Y6/2). Closely spaced fracture cleavage prominent in the upper half. | 2.91 |
| C-46 | Shale to siltstone, fine-grained, pale-olive (10Y6/2) and grayish-red (5R4/2). | 1.67 |
| C-45 | Siltstone, fine-grained, grayish-red (5R4/2). | 2.16 |
| C-44 | Shale, grayish-red (5R4/2). Prominent closely spaced fracture cleavage. | 1.33 |
| C-43 | Shale to siltstone, very fine grained, dark-grayish-red (5R3/2). Incipient fissility. | 3.33 |
| C-42 | Siltstone, fine-grained, dark-grayish-red (10R3/2). Prominent closely spaced fracture cleavage. | 10.5 |
| C-41 | Siltstone, coarse-grained, grayish-red (5R4/2). | 2.0 |
| C-40 | Siltstone, fine-grained, light-grayish-red (5R5/2). | 3.58 |
| C-39 | Siltstone, coarse-grained, to sandstone, very fine grained, pale-olive (10Y6/2). Upper 0.25 ft. of this unit is shale, yellowish-olive-brown (5Y5/4) with fracture cleavage. | 3.48 |
| C-38 | Sandstone, very fine grained, greenish-gray (5GY6/1). Upper 0.42 ft. is siltstone, fine-grained, greenish-gray (5G6/1). | 2.50 |
| C-37 | Sandstone, very fine grained, to siltstone, coarse-grained, greenish-gray (5GY6/1). The upper 0.33 ft. is siltstone, fine-grained, medium-light-gray (N6). | 1.83 |
| C-36 | Siltstone, medium-grained, yellowish-olive-brown (5Y5/4). Incipient fissility. | 0.83 |
| C-35 | Siltstone, coarse-grained, pale-olive (10Y6/2). | 5.25 |
| C-34 | Shale, light-olive-gray (5Y4/2). Fissile. | 0.75 |
| C-33 | Sandstone, very fine to fine-grained, light-olive-gray (5Y5/2). | 2.67 |
| C-32 | Siltstone, fine-grained, dark-greenish-gray (5GY4/1), fissile. | 5.0 |
| C-31 | Sandstone, very fine to fine-grained, light-olive-gray (5Y5/2). Massive. | 2.0 |
| C-30 | Siltstone, coarse-grained, to sandstone, very fine grained, light-grayish-olive (10Y5/2). Flaggy and fissile. | 5.0 |

| Unit | Lithologic description | Thickness (feet) |
|---|---|---|
| C-29 | Siltstone, coarse-grained, to sandstone, very fine grained, light-grayish-olive (10Y5/2). | 1.16 |
| C-28 | Shale to siltstone, fine-grained, dark-yellowish-gray (5Y6/2). | 2.0 |
| C-27 | Siltstone, medium- to fine-grained, grayish-red (10R4/2). Incipient fissility. | 3.75 |
| C-26 | Siltstone, fine-grained, dark-reddish-brown (10R3/4). | 1.67 |
| C-25 | Siltstone, medium-grained, dark-yellowish-gray (5Y6/2). Massive. | 1.33 |
| C-24 | Shale, pale-olive (10Y6/2). Fissile. | 4.33 |
| C-23 | Siltstone, medium-grained, pale-olive (10Y6/2). | 1.25 |
| C-22 | Siltstone, fine-grained, grayish-red (5R4/2). | 2.3 |
| C-21 | Shale, grayish-red (5R4/2). Fracture cleavage. | 2.16 |
| C-20 | Siltstone, fine-grained, dusky-red (5R3/4). | 4.0 |
| C-19 | Siltstone, coarse-grained, grayish-red (5R4/2). Massive. | 4.5 |
| C-18 | Shale, pale-olive (10Y6/2). Fissile. | 0.91 |
| C-17B | Shale and siltstone, medium-grained, medium-light-greenish-gray (5G7/1). | 1.0 |
| C-17A | Sandstone, very fine grained, pale-olive (10Y6/2). | 0.5 |
| C-16 | Shale, pale-olive (10Y6/2). Fissile, fracture cleavage. | 0.33 |
| C-15 | Shale, grayish-red (10R4/2). Fracture cleavage. | 3.0 |
| C-14 | Siltstone, medium-grained, grayish-red (5R4/2). | 0.67 |
| C-13 | Siltstone, fine-grained, grayish-red (10R4/2). Fracture cleavage. | 2.33 |
| C-12 | Shale to siltstone, fine-grained, grayish-red (10R4/2). Fissile. | 6.0 |
| C-11 | Shale, grayish-red (5R4/2). Fracture cleavage. | 4.83 |
| C-10 | Siltstone, coarse-grained, grayish-red (5R4/2). | 1.41 |
| C-9 | Shale to fine-grained siltstone, grayish-red (5R4/2). Fissile, fracture cleavage. | 18.0 |
| C-8 | Siltstone, coarse-grained, grayish-red (5R4/2). | 2.0 |
| C-7 | Shale, dusky-red (5R3/4). Fissile, fracture cleavage. | 33.0 |
| C-6 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2). | 2.0 |
| C-5 | Siltstone, fine-grained, dusky-red (5R3/4). Fissile, fracture cleavage. | 14.0 |
| C-4 | Siltstone, fine-grained, grayish-red (5R4/2). Incipient fissility. | 2.16 |
| C-3 | Siltstone, medium-grained, dark-reddish-brown (10R3/4). Fissile, fracture cleavage. | 4.0 |
| C-2 | Siltstone, coarse-grained, grayish-red (5R4/2). Massive. | 1.16 |
| C-1 | Shale, grayish-red (5R4/2). Fissile, fracture cleavage. | 4.67 |
| | Total | 2362.68 |

## SECTION 13

# PACKERTON MEMBER OF CATSKILL FORMATION

Type section of the Packerton Member of the Catskill Formation, located along railroad cuts on the west bank of the Lehigh River east-northeast of the town of Packerton (Figure 101). The top of a nearly complete section also occurs at the intersection of the paved road from Packerton and U.S. Route 209. Base of section is 6,150 feet south of latitude 40°52′30″ and 2,220 feet west of longitude 75°42′30″. Section measured by J. D. Glaeser.

| Unit | Lithologic description | Thickness (feet) |
|---|---|---|
| 265C | Sandstone, medium- to coarse-grained, medium-light-greenish-gray (5G7/1) and light-gray (N7). Top is truncated by crossbeds. | 3.16 |
| 265B | Sandstone, very fine to fine-grained, medium-light-gray (N6). | 8.0 |
| 265A | Sandstone, medium- to coarse-grained, medium-light-greenish-gray (5G7/1) and light-gray (N7). | 16.8 |
| 264 | Sandstone, fine-grained, light-gray (N7), fissile. | 0.25 |
| 263 | Sandstone, fine- to medium-grained, medium-gray (N5). | 19.0 |
| 262 | Shale, medium-gray (N5). | 0.75 |
| 261 | Sandstone, fine- to medium-grained, medium-dark-greenish-gray (5GY5/1); basal 0.5 ft. is siltstone, medium-grained, dark-greenish-gray (5GY4/1). Top truncated by unit 262. | 22.0 |
| 260 | Sandstone, fine- to medium-grained, medium-gray (N5). | 17.5 |
| 259 | Siltstone, fine-grained, medium-dark-gray (N4) in upper half, to dark-greenish-gray (5GY4/1) in lower half. | 1.0 |
| 258 | Sandstone, fine- to medium-grained, medium-light-gray (N6). Massive. | 2.16 |
| 257 | Sandstone, fine- to medium-grained, medium-bluish-gray (5B5/1). Upper 0.16 ft. is siltstone, medium-grained, light-bluish-gray (5B7/1). Fissile. | 0.66 |
| 256 | Sandstone, medium- to coarse-grained, medium-light-greenish-gray (5G7/1) in upper half and lower half sandstone, medium- to coarse-grained with conglomerate, medium-light-greenish-gray (5G7/1). Subrounded quartz granules. | 6.0 |
| 255 | Sandstone, coarse-grained, medium-bluish-gray (5B5/1). Wedges. | 5.83 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 254 | Sandstone, very coarse grained, to conglomerate, greenish-gray (5G6/1). Unit is massive, contains rounded quartz granules. | 4.58 |
| 253 | Sandstone, very fine to fine-grained, leached in the upper 1.67 ft., light-brownish-gray (5YR6/1). Massive. | 13.0 |
| 252 | Sandstone, medium-grained, medium-dark-greenish-gray (5G5/1). Massive. | 15.0 |
| 251 | Siltstone, fine- to medium-grained, olive-gray (5Y4/1). Platy, fissile. | 3.0 |
| 250 | Sandstone, medium- to coarse-grained, greenish-gray (5GY6/1). | 12.0 |
| 249 | Sandstone, fine-grained, moderate-brown (5YR3/4). Leached. | 2.0 |
| 248 | Sandstone, fine-grained, medium-dark-greenish-gray (5GY5/1). Massive. | 8.0 |
| 247 | Sandstone, medium-grained, medium-dark-greenish-gray (5GY5/1). Truncates unit 246. | 5.16 |
| 246 | Sandstone, fine-grained, medium-bluish-gray (5B5/1). Flaggy. Contains plant remains. | 2.0 |
| 245 | Leached quartz and shale, braided, dark-greenish-gray (5GY4/1). Calcareous, slightly conglomeratic. | 2.5 |
| 244 | Sandstone, fine-grained, dusky-yellow (5GY7/1). Upper 2.67 ft. is fine to medium grained, brownish gray (5YR4/1). | 13.0 |
| 243 | Sandstone, fine-grained, dark-greenish-gray (5GY4/1). Calcareous and leached at base and top. | 4.25 |
| 242 | Sandstone, fine-grained, medium-dark-greenish-gray (5GY5/1); lower 1 ft. deeply leached. | 3.33 |
| 241 | Sandstone, very fine to fine-grained, medium-dark-greenish-gray (5GY5/1) to medium-light-brownish-gray (5YR5/1). Massive. | 8.0 |
| 240 | Sandstone, fine-grained, medium-dark-greenish-gray (5GY5/1). Massive. | 1.33 |
| 239 | Siltstone, fine-grained, to shale, olive-gray (5Y4/1). Lower 6 in. deeply leached. | 3.16 |
| 238 | Sandstone, very fine grained, greenish-gray (5GY6/1). | 1.0 |
| 237 | Sandstone, fine-grained, medium-dark-greenish-gray (5GY5/1). | 1.58 |
| 236 | Shale, dark-greenish-gray (5GY4/1). | 0.75 |
| 235 | Sandstone, fine-grained, medium-dark-greenish-gray (5GY5/1). Massive. | 2.41 |
| 234 | Sandstone, fine-grained, greenish-gray (5G6/1). Massive. | 1.67 |
| 233 | Sandstone, fine- to medium-grained, moderate-brown (5YR3/4) to pale-yellowish-brown (10YR6/2). | 1.0 |
| 232 | Sandstone, fine-grained, greenish-gray (5GY6/1). Load casts at base. | 3.33 |
| 231 | Siltstone, medium- to fine-grained, dark-greenish-gray (5GY4/1). Loading. | 0.75 |
| 230 | Sandstone, fine-grained, medium-light-olive-gray (5Y5/1). Lower 8 in. leached. | 1.16 |
| 229 | Sandstone, very fine to fine-grained, medium-dark-greenish-gray (5GY5/1). Massive. | 5.5 |
| 228 | Sandstone, very fine to fine-grained, medium-dark-greenish-gray (5GY5/1). Massive. | 1.41 |
| 227E | Sandstone, very fine grained, medium-dark-greenish-gray (5GY5/1). | 7.5 |
| 227D | Sandstone, very fine grained, medium-light-gray (N6). | 2.16 |
| 227C | Sandstone, very fine to fine-grained, light-olive-gray (5Y6/1). | 1.5 |
| 227B$_3$ | Sandstone, fine-grained, medium-light-brownish-gray (5YR5/1). | 7.5 |
| 227B$_2$ | Sandstone, fine-grained. Shale-chip conglomerate, shale fragments, dark-greenish-gray (5GY4/1). | 0.5 |
| 227B$_1$ | Sandstone, fine-grained, medium-light-brownish-gray (5YR5/1). | 0.67 |
| 227A | Sandstone, very fine grained, medium-dark-greenish-gray (5GY5/1). | 17.0 |
| 226 | Siltstone, fine-grained, to shale, medium-light-olive-gray (5Y4/2). | 3.0 |
| 225 | Sandstone, fine-grained, medium-light-olive-gray (5Y5/1). | 5.67 |
| 224 | Siltstone, fine-grained, to shale, medium-light-olive-gray (5Y5/1). Platy. | 2.58 |
| 223 | Sandstone, fine- to very fine grained, medium-dark-greenish-gray (5GY5/1). Massive. | 6.67 |
| 222 | Siltstone, fine- to medium-grained, medium-dark- greenish-gray (5GY5/1). Incipient fissility. | 2.16 |
| 221B | Shale, grayish-red (10R4/2). | 1.0 |
| 221A | Siltstone, fine-grained, grayish-red (10R4/2). | 4.0 |
| 220 | Siltstone, fine-grained, grayish-red (5R4/2). | 7.33 |
| 219 | Siltstone, coarse-grained, grayish-red (5R4/2). Incipient platy fissility (¼ in.). | 3.83 |
| 218C | Sandstone, fine-grained, brownish-gray (5YR4/1). Massive. | 6.67 |
| 218B | Sandstone, fine-grained, light-olive-gray (5Y6/1). Massive. | 5.92 |
| 218A | Sandstone, fine-grained. Leached. | 0.75 |
| 217 | Siltstone, coarse-grained, medium-dark-greenish-gray (5GY5/1). Platy. | 2.0 |
| 216 | Sandstone, very fine grained, to siltstone, coarse-grained, greenish-gray (5GY6/1). | 2.0 |
| 215 | Siltstone, medium-grained, medium-dark-greenish-gray (5GY5/1). Platy to fissile. | 1.25 |
| 214 | Sandstone, very fine grained, greenish-gray (5GY6/1). Massive. | 5.5 |
| 213 | Sandstone, very fine grained, medium-dark-greenish-gray (5GY5/1). Deeply weathered. | 0.58 |
| 212 | Sandstone, fine-grained, medium-light-olive-gray (5Y5/1). Massive. | 23.0 |
| 211 | Siltstone, fine-grained, dark-yellow-green (5GY4/4). Incipient fissility. | 3.33 |
| 210 | Sandstone, fine-grained, greenish-gray (5GY6/1). Calcareous. Lower 1 ft. is leached. | 9.16 |
| 209 | Sandstone, fine-grained, greenish-gray (5GY6/1). Lower 8 in. is leached. | 7.08 |
| 208 | Sandstone, fine-grained, greenish-gray (5G6/1). | 1.5 |
| 207 | Sandstone, fine-grained, medium-dark-greenish-gray (5GY5/1). Thins upward. | 1.16 |
| 206 | Sandstone, fine-grained, greenish-gray (5GY6/1). Lower 3 in. leached and truncated by unit 207. | 1.41 |
| 205 | Shale, medium-bluish-gray (5B5/1). Incipient fissility. | 0.33 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 204C | Sandstone, fine- to medium-grained. | 3.5 |
| 204B | Sandstone, fine- to medium-grained with granule-sized calcareous shale fragments. | 0.8 |
| 204A | Sandstone, fine- to medium-grained. | 6.2 |
| 203 | Shale and siltstone, medium-grained, medium-dark-greenish-gray (5GY5/1). Interlaminated. | 0.83 |
| 202 | Sandstone, medium-grained, medium-light-olive-gray (5Y5/1). | 2.0 |
| 201 | Shale, dark-grayish-red (5R3/2) and olive-gray (5Y4/1). Colors mixed. Fissile. | 0.33 |
| 200B | Sandstone, fine-grained, dark-yellowish-gray (5Y6/2). Massive. | 1.33 |
| 200A | Sandstone, very fine grained, to siltstone, coarse-grained, brownish-gray (5YR4/1). Massive. | 1.67 |
| 199 | Sandstone, fine- to medium-grained, dark-yellowish-gray (5Y6/2). | 3.83 |
| 198 | Sandstone, medium-grained, greenish-gray (5GY6/1). | 1.67 |
| 197B | Sandstone, fine- to medium-grained, greenish-gray (5GY6/1). | 15.2 |
| 197A | Sandstone, medium-grained, medium-light-brownish-gray (5YR5/1). | 7.8 |
| 196D | Sandstone, medium-grained, dark-greenish-gray (5YR4/1). | 1.0 |
| 196C | Sandstone, medium-grained, medium-dark-greenish-gray (5GY5/1). Interlaminated and braided with shale, grayish-red (5R4/2). | 0.33 |
| 196B | Shale, medium-dark-greenish-gray (5GY5/1). | 0.42 |
| 196A | Sandstone, medium- to fine-grained, greenish-gray (5GY6/1). Basal unit rests directly upon topmost bed of Long Run Member. | 0.42 |
|  | Total | 416.02 |

## SECTION 14

# SAWMILL RUN MEMBER OF CATSKILL FORMATION

Type section of the Sawmill Run Member of the Catskill Formation, located along the west bank of the Lehigh River east-northeast of the town of Packerton (Figure 101). Base of section is 5,650 feet south of latitude 40°52′30″ and 2,420 feet west of longitude 75°42′30″. Section measured by J. D. Glaeser.

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 331 | Siltstone, fine-grained, and shale, olive-gray (5Y4/1). Incipient fissility. | 0.83 |
| 330 | Siltstone, medium-grained, brownish-gray (5YR4/1). Massive. | 1.0 |
| 329 | Siltstone, medium-grained, grayish-red (5R4/2). Fracture cleavage crumbly. | 3.33 |
| 328 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2). Grooved weathered surfaces. Incipient platy fissility. | 7.0 |
| 327 | Sandstone, very fine to fine-grained, grayish-red (5R4/2). Massive. | 2.5 |
| 326 | Sandstone, very fine grained, and siltstone, coarse-grained, grayish-red (5R4/2) with thin dark-grayish-red (10R3/2) shales (fissile with clean fractures) at top and bottom. | 0.96 |
| 325B | Sandstone, very fine grained, grayish-red (5R4/2). Massive. | 2.24 |
| 325A | Shale, fissile, and coarse-grained siltstone, grayish-red (5R4/2) in zone above basal sandstone, 0.44 ft. thick. Very fine grained sandstone, massive, in lower 0.5 ft. | 0.94 |
| 324 | Siltstone, medium-grained, grayish-red (5R4/2). Fracture cleavage. | 9.5 |
| 323 | Siltstone, medium-grained, grayish-red (5R4/2). Massive. Incipient fracture cleavage. | 5.83 |
| 322 | Sandstone, very fine grained, and siltstone, coarse-grained, light-grayish-brown (5YR4/2). Massive. | 9.0 |
| 321 | Siltstone, fine-grained, grayish-red (5R4/2). Incipient fracture cleavage. | 2.75 |
| 320 | Siltstone, coarse-grained, grayish-red (5R4/2). | 2.25 |
| 319 | Sandstone, very fine grained, medium-light-brownish-gray (5YR5/1). Basal 8 in. is interlaminated siltstone and shale, grayish-red (5R4/2). | 6.83 |
| 318B | Siltstone, medium-gray (N5). Incipient fissility. Basal 0.04 ft. is shale, brownish-gray (5YR4/1). | 0.21 |
| 318A | Siltstone, medium-gray (N5). Incipient fissility. | 0.17 |
| 317 | Sandstone, very fine grained, medium-gray (N5). Massive. | 1.67 |
| 316E | Sandstone, very fine to fine-grained, medium-light-brownish-gray (5YR5/1). Massive. | 8.0 |
| 316D | Calcareous sandstone, brownish-gray (5YR4/1), crystalline. Leached. Massive. | 1.0 |
| 316C | Sandstone, very fine to fine-grained, greenish-gray (5GY6/1). Massive. | 16.25 |
| 316B | Calcareous sandstone, light-brownish-gray (5YR6/1), crystalline. Leached. Massive. | 0.25 |
| 316A | Sandstone, very fine to fine-grained, greenish-gray (5GY6/1). Massive. | 9.0 |
| 315 | Siltstone, medium- to coarse-grained, greenish-gray (5GY6/1). | 2.75 |
| 314 | Sandstone, fine-grained, greenish-gray (5G6/1). | 4.33 |
| 313 | Sandstone, very fine to fine-grained, greenish-gray (5GY6/1 to 5/1). Alternating massive and flaggy beds. | 3.0 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 312 | Sandstone, very fine grained, to siltstone, coarse-grained, medium-dark-greenish-gray (5GY5/1). Flaggy. | 0.75 |
| 311 | Sandstone, fine- to medium-grained, greenish-gray (5G6/1). | 2.0 |
| 310 | Calcareous sandstone, medium-light-gray (N6). Deeply weathered. High clay content. | 2.5 |
| 309I | Sandstone, fine-grained, medium-light-gray (N6). | 10.0 |
| 309H | Sandstone, fine-grained. Calcareous. Leached. | 0.42 |
| 309G | Sandstone, fine-grained, medium-gray (N5). | 0.5 |
| 309F | Sandstone, fine-grained. Calcareous. Leached. | 0.33 |
| 309E | Sandstone, fine-grained, medium-gray (N5). | 3.5 |
| 309D | Sandstone, fine-grained. Calcareous. Leached. | 0.33 |
| 309C | Sandstone, fine-grained, medium-gray (N5). | 1.25 |
| 309B | Sandstone, fine-grained. Calcareous. Leached. | 0.16 |
| 309A | Sandstone, fine-grained, medium-gray (N5). Calcareous. Leached. | 0.5 |
| 308 | Siltstone, brownish-gray (5YR4/1), coarse-grained, platy. Interbedded with shale, dark-grayish-red (5R3/2), fissile. | 0.33 |
| 307 | Sandstone, very fine to fine-grained, brownish-gray (5YR4/1). Massive. | 1.0 |
| 306 | Siltstone, coarse-grained, grayish-red (5R4/2), interbedded with shale, dark-grayish-red (5R3/2). | 0.41 |
| 305 | Sandstone, very fine to fine-grained, medium-light-olive-gray (5Y5/1) to brownish-gray (5YR4/1). Flaggy. Individual beds wedge out. | 3.5 |
| 304 | Sandstone, fine- to medium-grained, medium-gray (N5). Flaggy. | 13.5 |
| 303 | Sandstone, fine- to medium-grained, medium-light-gray (N6). | 7.5 |
| 302 | Calcareous sandstone, dark-greenish-gray (5GY4/1), leached. Crystalline. High clay content. | 1.0 |
| 301 | Sandstone, fine-grained, medium-dark-greenish-gray (5GY5/1). Massive. | 9.0 |
| 300 | Calcareous sandstone, light-olive-gray (5G6/1), leached. High clay content. | 1.5 |
| 299 | Sandstone, very fine to fine-grained, greenish-gray (5G6/1). | 10.0 |
| 298 | Shale, olive-gray (5Y4/1). Incipient fissility. | 0.67 |
| 297 | Sandstone, very fine to fine-grained, medium-dark-greenish-gray (5GY5/1). Massive. | 9.0 |
| 296 | Sandstone, very fine to fine-grained, medium-dark-greenish-gray (5GY5/1). Calcareous. Shale fragments to 4 mm. | 0.67 |
| 295 | Sandstone, fine-grained, greenish-gray (5GY6/1). | 2.5 |
| 294 | Shale, dark-greenish-gray (5GY4/1). | 0.58 |
| 293C | Sandstone, fine-grained, medium-dark-greenish-gray (5GY5/1). | 7.0 |
| 293B | Sandstone, fine-grained. Leached and pitted. | 1.0 |
| 293A | Sandstone, fine-grained, medium-dark-greenish-gray (5GY5/1). | 3.0 |
| 292 | Sandstone, very fine grained, medium-dark-greenish-gray (5GY5/1). Massive. Leached in top 2 ft. | 7.0 |
| 291 | Siltstone, fine-grained, and shale, dark-greenish-gray (5GY4/1). Coarse-grained leached calcite patches. | 1.5 |
| 290 | Sandstone, fine- to medium-grained, greenish-gray (5GY6/1). Massive. Base channels unit 289. | 6.0 |
| 289 | Sandstone, fine-grained, greenish-gray (5G6/1). | 3.33 |
| 288 | Siltstone, fine-grained, grayish-red (5R4/2). Incipient fissility. | 10.0 |
| 287 | Siltstone, fine-grained, dusky-red (5R3/4). Massive. | 4.16 |
| 286 | Siltstone, medium-grained, grayish-red (5R4/2). Incipient fissility. | 4.0 |
| 285B | Siltstone, coarse-grained, grading to medium-grained in upper 2.33 ft., pale-red (5R6/2) to light-grayish-red (5R5/2). Massive. | 15.68 |
| 285A | Sandstone, very fine grained, greenish-gray (5GY6/1). | 0.75 |
| 284 | Sandstone, very fine to fine-grained, greenish-gray (5GY6/1). Beds pinch out. | 4.58 |
| 283 | Sandstone, very fine grained, massive, medium-dark-greenish-gray (5GY5/1). Top leached. | 1.67 |
| 282 | Siltstone, coarse-grained, light-grayish-red (5R5/2). | 3.0 |
| 281 | Sandstone, very fine to fine-grained, brownish-gray (5YR4/1). Massive. | 16.0 |
| 280 | Covered. | 11.0 |
| 279 | Sandstone, very fine to fine-grained, greenish-gray (5GY6/1). | 8.75 |
| 278 | Covered. | 25.80 |
| 277 | Sandstone, very fine grained, medium-light-gray (N6). Massive. | 11.10 |
| 276 | Sandstone, very fine to fine-grained, medium-light-brownish-gray (5YR5/1). | 7.74 |
| 275 | Sandstone, fine-grained, greenish-gray (5G6/1). Massive. | 2.0 |
| 274 | Sandstone, very fine grained, to siltstone, coarse-grained, medium-gray (N5). Flaggy. | 4.0 |
| 273 | Sandstone, very fine grained, to siltstone, coarse-grained, medium-gray (N5). Massive. | 14.0 |
| 272 | Sandstone, very fine grained, medium-dark-greenish-gray (5G5/1). | 0.58 |
| 271 | Sandstone, fine-grained, medium-light-gray (N6). Deeply weathered in basal 0.16 ft. Contains plant remains. | 5.58 |
| 270 | Sandstone, fine- to medium-grained, medium-light-gray (N6). Lower 8 in. is deeply weathered. | 2.5 |
| 269 | Sandstone, fine- to medium-grained, medium-light-olive gray (5Y5/1). Massive. | 2.0 |
| 268 | Siltstone, fine-grained, to shale, brownish-gray (5Y4/1) to grayish-red (5R4/2). (Colors mixed.) | 1.0 |
| 267 | Siltstone, medium-grained, grayish-red (5R4/2). | 51.0 |
| 266 | Siltstone, medium-grained, grayish-red (5R4/2). | 3.67 |
|  | Total | 424.38 |

## SECTION 15

# BERRY RUN MEMBER OF CATSKILL FORMATION

Type section of the Berry Run Member of the Catskill Formation, located on the west side of the Lehigh River along the former railroad, where the member is almost fully exposed (Figure 101). Base of section is 5,310 feet south of latitude 40°52′30″ and 2,680 feet west of longitude 75°42′30″. Section measured by J. D. Glaeser.

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 417 | Siltstone, grayish-red (5R4/2). | 5.58 |
| 416 | Sandstone, very fine grained, grayish-red (5R4/2). | 2.67 |
| 415 | Shale, dark-reddish-brown (10R3/4). Fissile. | 0.33 |
| 414 | Sandstone, very fine grained, light-grayish-red (5R5/2). Micaceous. | 3.0 |
| 413 | Siltstone, fine-grained, dusky-moderate-red (5R4/4). Fracture cleavage. | 4.83 |
| 412 | Sandstone, very fine-grained, to coarse-grained siltstone, micaceous. Grades upward into micaceous siltstone to fine-grained siltstone, light-grayish-red (5R5/2). | 11.5 |
| 411 | Covered. | 495.0 |
| 410 | Sandstone, very coarse to coarse-grained, yellowish-gray (5Y7/2); contains conglomerate with granule-size quartz. Granules are less than 1% of rock unit. | 4.33 |
| 409 | Sandstone, very fine grained, dark-greenish-gray (5GY4/1). | 1.25 |
| 408 | Sandstone, coarse- to very coarse grained. Tough, massive. | 2.33 |
| 407 | Siltstone, flaggy bedding, medium-light- gray (N6). | 0.5 |
| 406 | Sandstone, medium-grained, dark-yellowish-gray (5Y6/2). Upper 3.33 ft. is very coarse to coarse-grained sandstone with occasional quartz granules, yellowish-gray (5Y7/2). | 11.5 |
| 405 | Sandstone, medium- to fine-grained, light-olive-gray (5Y5/2). Partly covered. | 47.0 |
| 404 | Covered. | 27.6 |
| 403 | Sandstone, coarse- to medium-grained, tough, greenish-gray (5GY6/1), varies to dark-greenish-gray (5GY4/1). Steep bipolar crossbeds in lower 10 ft. Planar flaggy beds in upper 15 ft. | 38.0 |
| 402 | Siltstone, fine-grained, medium-dark-greenish-gray (5GY5/1), micaceous. | 0.67 |
| 401 | Sandstone, coarse- to medium-grained, with scattered subangular quartz pebbles, very tough, breaks through grains, greenish-gray (5GY6/1). Massive and flaggy, although bedding not distinct. Steep, SE-dipping flaggy crossbeds in upper 1 ft.* | 12.0 |
| 400 | Sandstone, medium-grained in lower 4 ft. and fine- to very fine grained above. Tough and vitreous, medium-light-gray (N6). Lower 3.0 ft. is massive, NW-dipping, bevelled by SE-dipping surface with downward thickening wedge above it. Beds above not distinct but appear to be planar flags. | 16.0 |
| 399 | Sandstone, medium- to fine-grained. Massive and pitted. Tough, calcareous, leached, light-gray (N7). | 3.67 |
| 398 | Sandstone, medium- to fine-grained, massive, medium-light-gray (N6). Parallel-laminated. Slightly NW dipping. | 7.0 |
| 397 | Sandstone, fine-grained in lower 0.33 ft., very fine grained above, light-olive-gray (5Y6/1). Planar flags. | 1.83 |
| 396 | Sandstone, fine- to medium-grained. Basal 4.0 ft. is steep NW-dipping flags. Massive above, planar but indistinct. Medium-light gray (N6). | 10.0 |
| 395C | Siltstone, medium- to fine-grained. Unit is lens shaped and pinches out. Incipient fracture cleavage. Color is a mixture of grayish red (5R4/2) and medium-light-olive gray (5Y5/1). | 0.41 |
| 395B | Sandstone, fine-grained, tough, vitreous. Thickens both upward and downward in exposure, medium-gray (N5). | 0.5 |
| 395A | Siltstone, medium- to fine-grained, color is a mixture of grayish red (5R4/2) and medium-light-olive gray (5Y5/1). Incipient fracture cleavage. | 0.5 |
| 394 | Sandstone, fine-grained, light-olive-gray (5YR6/1). Tough, vitreous, micaceous. Individual beds wedge out in exposure. All are flags, dipping steeply NW. | 1.67 |
| 393 | Calcareous sandstone, basal part has high clay content and scattered shale fragments which are grayish red (5R4/2); matrix is greenish gray (5G6/1). Remainder of unit is sandstone, fine-grained, slightly calcareous, tough, massive, medium-light-gray (N6). | 4.33 |
| 392 | Sandstone, fine-grained, medium-light-gray (N6), flaggy-bedded, wedge-shaped units, thin downward in exposure. Tough. Basal 1.0 ft. is flaggy and has a steep NW dip. Above, beds are flaggy and gently SE dipping. Upper 1.0 ft. is coarse-grained siltstone with color mixture of grayish red (5R4/2) and greenish gray (5G6/1). | 2.33 |
| 391 | Sandstone, fine- to medium-grained, medium-light-gray (N6). Topmost beds are truncated by overlying unit and thin upward in the exposure. Beds are massive, parallel laminated in lower 7.0 ft. Top 2.5 ft. is thick, NW-dipping flags. Top bed is planar flagstone which wedges out upward. Top of unit is 1 ft. above an anchored steel cable, the other end of which is attached to a power pole above the exposure. | 9.5 |

* Qualitative statements of dip directions refer to primary orientation prior to bed deformation.

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 390 | Sandstone, very fine grained, medium-gray (N5). Micaceous. Beds are probably flaggy but fracture cleavage obscures bed structure. | 3.25 |
| 389 | Sandstone, fine-grained, medium-light-olive-gray (5Y5/1). Planar massive beds at base, grade up into planar flaggy units. | 13.0 |
| 388 | Sandstone, fine- to medium-grained, fresh color is medium-dark-greenish gray (5G5/1). Micaceous, massive, deeply weathered. Weathers to a rusty-red-brown color in the outer 1 in. to 2 in. | 2.0 |
| 387 | Sandstone, medium- to fine-grained, greenish-gray (5GY6/1). Massive, tough, vitreous. | 5.83 |
| 386 | Sandstone, medium- to fine-grained, medium-light-gray (N6). Tough, vitreous. Partly covered. | 12.0 |
| 385 | Sandstone, fine-grained. Flaggy, tough, medium-gray (N5). | 3.16 |
| 384 | Sandstone, medium- to fine-grained, medium-dark-greenish-gray (5GY5/1). Micaceous. Planar massive bedding. | 14.0 |
| 383 | Covered. | 12.0 |
| 382 | Sandstone, lower 0.83 ft. is fine to very fine grained, micaceous, greenish-gray (5GY6/1). Grades upward to fine- to very fine grained tough sandstone, brownish-gray (5YR4/1). There is a bedding break between these color variants. Lower 2 ft. is planar, massive beds. Overlying 2 ft. is gently SE dipping flags. Above are planar flags. Bed orientation, N58E, 80NW. | 12.0 |
| 381 | Sandstone, medium- to fine-grained, medium-light-brownish-gray (5YR5/1). Contains a few scattered thin gray-red shale blebs. Lower half is massive; upper half is very gently SE dipping flags. Top truncated by overlying unit. | 2.41 |
| 380 | Siltstone with irregular blebs of gray-red shale, dark-bluish-gray (5B4/1). Pinched out upward. | 0.33 |
| 379 | Sandstone, fine- to very fine grained, dark-greenish-gray (5GY4/1). Basal 0.16 ft. leached and pitted and this leached zone pinches out upward. | 4.33 |
| 378 | Sandstone, medium-grained. Tough, breaks through grains. Basal 0.58 ft. is leached, pitted calcareous siltstone, dark-greenish-gray (5GY4/1). Lower 4.0 ft. is massive, bedding not distinct. Overlying 4.0 ft. is SE dipping (8°), with very gently NW dipping flags above. | 12.16 |
| 377 | Siltstone, fine-grained, dark-greenish-gray (5GY4/1). Fracture cleavage. | 0.75 |
| 376 | Sandstone, medium-grained, medium-light-gray (N6). Massive in lower third. Tough, breaks through grains, lower 3.0 ft. massive; above, 5° to 10° NW-dipping flags. | 6.5 |
| 375 | Sandstone, very fine grained, medium-gray (N5). Beds 2 to 3 in. thick. | 1.33 |
| 374 | Sandstone, medium- to fine-grained, medium-light-gray (N6). Lower 2.0 ft. has planar massive bedding. Overlying 2.0 ft. has NW-dipping flaggy crossbeds. Above, planar, massive. | 11.33 |
| 373 | Siltstone, medium- to fine-grained, medium-gray (N5). | 0.33 |
| 372 | Sandstone, medium- to fine-grained, tough, breaks through grains, medium-light-brownish-gray (5YR5/1). Basal 0.83 ft. is leached and pitted tough calcareous sandstone with a high clay content, medium-light-greenish-gray (5G7/1). Unit above leached zone has steep NW-dipping foreset wedges. Leached zone may also be NW dipping. | 4.5 |
| 371 | Sandstone, fine-grained, massive, greenish-gray (5GY6/1). Lower 0.16 ft. is leached and pitted, contains rounded pods of gray-red shale in matrix of tough calcareous medium-grained sandstone, light-bluish-gray (5B7/1). | 5.0 |
| 370 | Siltstone, fine-grained, dark-grayish-red (10R3/2). Incipient fissility. | 0.5 |
| 369 | Sandstone, fine-grained, medium-light-brownish-gray (5YR5/1). Breaks through grains. Basal third is a downward-thickening wedge with steep NW dips. | 2.75 |
| 368 | Sandstone, medium- to fine-grained. Planar flags. Tough, breaks through grains. Base of a 0.25-ft. leached and pitted zone occurs 2.58 ft. above base of unit. Top 1.0 ft. has NW-dipping flags. Topmost bed is bevelled by SE-dipping bed of unit above, and leached zone fills in as wedge between them. | 8.08 |
| 367 | Sandstone, medium-grained, planar, massive beds, medium-light-gray (N6). | 1.91 |
| 366 | Sandstone, fine- to medium-grained, greenish-gray (5GY6/1). Base of a leached, pitted zone occurs 0.33 ft. below top; tough, breaks through grains. | 2.0 |
| 365 | Siltstone, medium- to coarse-grained, medium-gray (N5). Deeply weathered, leached and pitted. | 0.58 |
| 364 | Sandstone, medium-grained, olive-gray (5Y4/1). Massive, very tough. Deeply weathered below the outer 1-in. surface rind. | 0.75 |
| 363 | Calcareous sandstone with sparry calcite. Deeply weathered, leached, and pitted. Contains scattered fine-grained rock fragments. Dominantly red and green shale. | 0.83 |
| 362 | Siltstone, coarse-grained, medium-light-gray (N6). Micaceous. Parallel-laminated flags, planar-bedded. Top surface cut down by leached zone and contact dips NW. | 2.33 |
| 361 | Sandstone, coarse-grained, greenish-gray (5GY6/1). Tough, breaks through grains. Lower 0.41 ft. is leached and pitted and is conglomeratic, containing scattered subrounded quartz granules. Matrix of conglomerate is tough, coarse-grained calcareous sandstone, greenish-gray (5G6/1). Entire unit dips 10° NW. Top bevelled by unit 362. Unit 361 is the front of an advancing bar. | 2.33 |

| Unit | Lithologic description | Thickness (feet) |
|---|---|---|
| 360 | Sandstone, coarse- to medium-grained, medium-dark-greenish-gray (5GY5/1). Vitreous, tough, breaks through grains. Upper 1.83 ft. is fine-grained sandstone, medium-dark-greenish-gray (5GY5/1), flaggy bedded, with basal part greenish-gray (5GY6/1). Well-developed NW-dipping flags in lower 3.0 ft. In overlying 0.67 ft. are planar flags overlain by very gently SE dipping flags. | 4.75 |
| 359 | Shale, incipient fissility, greenish-gray (5GY6/1). Bed orientation N46E, 84NW. | 3.33 |
| 358 | Sandstone, coarse- to medium-grained, medium-dark-greenish-gray (5G5/1). Breaks through grains. Conglomeratic, especially in upper two-thirds. Contains scattered subangular quartz granules. Base massive. In upper half of unit are NW-dipping wedges at eye level and above are SE-dipping wedges. Unit is a preserved dune crest. | 4.5 |
| 357 | Sandstone, very coarse grained, greenish-gray (5GY6/1), massive. Contains few scattered granules of quartz. Unit thickens downward in exposure. Thins to zero 8.0 ft. above ground level. | 0.83 |
| 356 | Sandstone, coarse- to very coarse grained, greenish-gray (5G6/1). Tough, vitreous, breaks through grains. Conglomeratic, containing scattered subrounded quartz granules. Massive flags; top 1.0 ft. of unit, high in exposure, has SE-dipping bevelled surface with NW-dipping wedges resting on it. | 3.0 |
| 355 | Sandstone, medium-grained, greenish-gray (5G6/1). Tough, vitreous, breaks through grains. Massive flags. Top 1.0 ft. is a NW-dipping wedge. | 4.0 |
| 354 | Sandstone, coarse- to medium-grained, greenish-gray (5GY6/1). Top 0.04 ft. is micaceous fine siltstone with incipient fissility. | 0.25 |
| 353 | Sandstone, very fine grained, to coarse-grained siltstone, medium-dark-greenish-gray (5GY5/1). Breaks through grains. Indistinct flaggy bedding. | 1.75 |
| 352 | Sandstone, coarse-grained, medium-light-greenish-gray (5G7/1). Tough, vitreous, breaks through grains. Lower two-thirds massive; upper third is a SE-dipping plane with flaggy beds building in toward it. Unit wedges out upward in exposure. | 3.16 |
| 351 | Sandstone, tough, massive, calcareous. Leached and pitted. Contains scattered subangular rock fragments and quartz. | 2.5 |
| 350 | Sandstone, coarse- to medium-grained, medium-light-bluish-gray (5B6/1). Vitreous, breaks through grains. Massive, bedding not distinct. | 8.5 |
| 349 | Siltstone, fine-grained, medium-gray (N5). Incipient fissility. | 0.5 |
| 348 | Sandstone, medium-grained, greenish-gray (5G6/1). Tough, vitreous, breaks through grains. Contains scattered flat shale pods of granule size. SE- and NW-dipping, flaggy crossbeds which change quadrant direction along length of outcrop, preserving crest of underlying dune. | 13.0 |
| 347 | Sandstone, medium-grained, greenish-gray (5G6/1). Tough, vitreous, breaks through grains. Massive, bedding not distinct. | 5.16 |
| 346 | Sandstone, fine-grained, medium-dark-greenish-gray (5GY5/1). Tough, breaks through grains. Planar flags. | 5.83 |
| 345 | Sandstone, medium-grained, medium-dark-greenish-gray (5GY5/1). Micaceous, tough. At base is SE-dipping wedge which thins downward in exposure. In middle, 6.0 ft. of planar, massive beds. Top contains gently SE dipping flags. | 8.0 |
| 344 | Sandstone, medium-grained, greenish-gray (5GY6/1). Tough, vitreous, breaks through grains. Contains thin, flat, shale pods in basal portion. Bedding not distinct. | 6.0 |
| 343 | Sandstone, fine-grained, greenish-gray (5GY6/1). Partly covered. Tough, vitreous, breaks through grains. NW-dipping wedges at 8° to 10°. | 7.5 |
| 342 | Sandstone, medium-grained, light-olive-gray (5Y6/1). Micaceous, breaks through grains. Flaggy bedding. | 1.0 |
| 341 | Sandstone, fine-grained, greenish-gray (5GY6/1). Tough, vitreous, breaks through grains. Gently NW dipping crossbed wedges. Massive unit. | 8.0 |
| 340 | Sandstone, fine-grained, medium-dark-greenish-gray (5GY6/1). Tough, breaks through grains. Thin, parallel-laminated flaggy beds (1 in. thick). | 0.83 |
| 339 | Sandstone, fine-grained, medium-dark-greenish-gray (5G5/1). Tough, vitreous, parts into units 2 in. to 4 in. thick. Beds flaggy | 5.33 |
| 338 | Sandstone, fine-grained, light-olive-gray (5Y6/1). Irregularly fractured. Bedding not distinct. | 1.5 |
| 337 | Sandstone, fine-grained, light-olive-gray (5Y6/1). Massive, parallel-laminated. | 2.0 |
| 336 | Sandstone, medium- to fine-grained, light-gray (N7). SE-dipping crossbed wedges. Upper half more weathered than lower half. | 4.5 |
| 335 | Sandstone, coarse- to medium-grained, medium-light-gray (N6). Planar flaggy bedding. | 2.5 |
| 334 | Sandstone, medium- to fine-grained, medium-dark-greenish-gray (5GY5/1). Tough, vitreous, breaks through grains. Massive to flaggy bedding. | 3.58 |
| 333 | Sandstone, medium- to fine-grained, greenish-gray (5G6/1). Breaks through grains. Unit has fissile shale bed 4 in. thick, the base of which is 4 in. above base of unit 333. Shale is dark greenish gray (5GY4/1), thins downward in the exposure, where sandstone beds merge. The upper sandstone thins upward in exposure. Upward in exposure unit 333 is comprised of two subequal beds: an upper sandstone and a lower shale. | 0.91 |
| 332 | Sandstone, coarse- to medium-grained, light-bluish-gray (5B7/1). Tough, vitreous, breaks through grains. NW-dipping flaggy crossbeds. | 1.16 |
|  | Total | 984.97 |

# SECTION 16

## CLARK'S FERRY MEMBER OF CATSKILL FORMATION

Reference section of the Clark's Ferry Member of the Catskill Formation, located on the west bank of the Lehigh River in roadcuts on U.S. Route 209 just south of the town of Jim Thorpe (Figure 101). Base of section is 4,560 feet south of latitude 40°52′30″ and 3,820 feet west of longitude 75°42′30″. Section measured by J. D. Glaeser.

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 36 | Siltstone, medium-grained, dark-greenish-gray (5GY4/1). Flaggy. | 5.0 |
| 35 | Sandstone, fine- to coarse-grained, light-bluish-gray (5B7/1) and brownish-gray (5YR4/1), massive. | 20.0 |
| 34B | Shale and coarse-grained siltstone. | 2.0 |
| 34A | Sandstone, medium- and very coarse grained, medium-brownish-gray (5R5/1). Poorly sorted. | 9.3 |
| 33B | Sandstone, medium- to coarse-grained, medium-light-brownish-gray (5YR5/1). Becomes increasingly conglomeratic upward. | 14.3 |
| 33A | Sandstone, coarse- to very coarse grained. Scattered granules—conglomeratic. | 14.3 |
| 32 | Sandstone, fine- to medium-grained, light-grayish-red (5R5/2). | 5.0 |
| 31 | Sandstone, medium- to very coarse grained, medium-dark-greenish-gray (5GY5/1). Many crossbeds. | 5.5 |
| 30 | Sandstone, fine- to medium-grained, medium-light-brownish-gray (5YR5/1). | 6.0 |
| 29 | Sandstone, medium- to very coarse grained, medium-light-olive-gray (5Y5/1) to light-bluish-gray (5B7/1). Contains pebbles, is increasingly conglomeratic in upper half. Massive. | 16.9 |
| 28 | Sandstone, fine- to medium-grained, medium-light-olive-gray (5Y5/1). Massive. Mixed shale and sandstone at base. | 14.48 |
| 27 | Sandstone, very fine to fine-grained, medium-dark-greenish-gray (5GY5/1). Many crossbeds. | 2.92 |
| 26B | Sandstone, coarse- to very coarse grained, medium-light-bluish-gray (5B6/1). Conglomeratic, scattered fragments. | 14.5 |
| 26A | Sandstone, fine-grained, light-olive-gray (5Y6/1). | 14.6 |
| 25B | Sandstone, medium-grained, medium-light-bluish-gray (5B6/1). Conglomeratic. Fragments scattered on bedding planes. | 6.2 |
| 25A | Sandstone, fine-grained, grayish-red (5R4/2). Massive slabs. | 12.6 |
| 24 | Sandstone, coarse- to very coarse grained, medium-light-bluish-gray (5B6/1). Conglomeratic. | 13.3 |
| 23 | Sandstone, medium- to coarse-grained, medium-light-olive-gray (5Y5/1) and olive-gray (5Y4/1). Conglomeratic. Scattered pebbles in lower half, crossbeds in upper half. | 101.0 |
| 22 | Sandstone, coarse-grained. Red and green shale fragments. | 6.0 |
| 21 | Sandstone, coarse-grained, grading upward into fine-grained, medium-light-olive-gray (5Y5/1) and light-olive-gray (5Y6/1). Massive. Upper half has crossbeds. | 32.9 |
| 20 | Covered. | 28.0 |
| 19 | Sandstone, medium- to coarse-grained, medium-light-olive-gray (5Y5/1). Pebble conglomerate bed; shale and quartz pebbles in top 0.1 ft., ripple marks at top of lower half. | 20.9 |
| 18 | Sandstone, medium- to coarse-grained, light-olive-gray (5Y6/1). Conglomeratic. Yellow-green rock fragments, quartz pebbles in top few inches. | 2.5 |
| 17 | Sandstone, medium- to coarse-grained, medium-light-olive-gray (5Y5/1). | 6.0 |
| 16 | Sandstone, coarse- to very coarse grained, medium-light-olive-gray (5Y5/1). Conglomeratic. Massive. | 25.9 |
| 15C | Sandstone, coarse-grained, moderate-yellowish-brown (10YR5/4). | 9.4 |
| 15B | Siltstone, fine-grained, medium-light-olive-gray (5Y5/1), interbedded with sandstone, medium-grained, greenish-gray (5GY6/1). | 6.0 |
| 15A | Sandstone, medium-grained, medium-dark-greenish-gray (5GY5/1). | 9.3 |
| 14 | Sandstone, fine- to medium-grained, light-olive-gray (5Y6/1), flaggy. Fissile shale, top 0.16 ft., medium-light-olive-gray (5Y5/1). Grades from below. | 2.64 |
| 13 | Sandstone, medium- to coarse-grained, medium-dark-greenish-gray (5GY6/1—5GY5/1). Flaggy to massive. | 18.7 |
| 12 | Sandstone, fine- to medium-grained, medium-light-olive-gray (5Y5/1). Occasional coarse-grained sandstone and scattered quartz pebbles. | 93.2 |
| 11 | Sandstone, medium- to coarse-grained, light-olive-gray (5Y6/1). Conglomeratic. | 13.6 |
| 10 | Sandstone, medium- to coarse-grained, pale-orange (10YR7/2). | 30.7 |
| 9D | Sandstone, medium- to coarse-grained. Beds indistinct with high clay content. | 20.6 |
| 9C | Sandstone, medium- to coarse-grained, very pale orange (10YR8/2). Massive. | 2.0 |
| 9B | Siltstone, medium-grained, greenish-gray (5G6/1). | 2.5 |
| 9A | Sandstone, medium- to coarse-grained, greenish-gray (5GY6/1). Massive. | 3.0 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 8B | Sandstone, medium- to coarse-grained, grayish-orange (10YR7/4). Scattered conglomerate. Crossbeds in upper 10 ft. | 21.2 |
| 8A | Sandstone, medium- to coarse-grained, grayish-orange (10YR7/4). Conglomeratic. | 10.6 |
| 7 | Sandstone, medium- to coarse-grained, grayish-orange (10YR7/4). Scattered granules. | 15.4 |
| 6 | Sandstone, medium- to coarse-grained, grayish-orange (10YR7/4). Conglomeratic. Few quartz and shale fragments on tops of beds. | 14.3 |
| 5 | Sandstone, medium-grained, light-bluish-gray (5B7/1). | 55.4 |
| 4 | Sandstone, coarse- to very coarse grained, greenish-gray (5GY6/1), conglomeratic, with pebble content decreasing upward. | 22.3 |
| 3B | Shale to fine-grained siltstone, dusky-red (5R3/4). Mixed red and grayish-green colors in upper 1.0 ft. | 5.9 |
| 3A | Sandstone, fine- to medium-grained, medium-light-brownish-gray (5YR5/1). | 3.0 |
| 2B | Sandstone, fine- to medium-grained, light-olive-gray (5Y6/1) and greenish-gray (5GY6/1). Top of unit is brownish-orange pink (5YR7/4). Few shale and quartz fragments. Flaggy. Massive. | 111.0 |
| 2A | Sandstone, fine-grained, grades up to siltstone, medium-grained, greenish-gray (5GY6/1). | 4.0 |
| 1C | White quartz-pebble conglomerate. | 4.0 |
| 1B | Sandstone, medium- to very coarse grained, greenish-gray (5GY6/1) and dark-greenish-gray (5GY4/1). | 22.7 |
| 1A | White quartz-pebble conglomerate. | 2.5 |
|  | Total | 904.04 |

# SECTION 17

## DUNCANNON MEMBER OF CATSKILL FORMATION

Reference section of the Duncannon Member of the Catskill Formation, located in roadcuts along U.S. Route 209 toward the southern limits of the town of Jim Thorpe on the west bank of the Lehigh River (Figure 101). The top of the Duncannon (units 80-97D) is not exposed there, but occurs on the east bank of the Lehigh River at the entrance to the town's sewage disposal plant. Base of section is 6,000 feet south of latitude 40°52′30′′ and 3,900 feet east of longitude 75°45′. Contact of Duncannon Member with base of Spechty Kopf Formation is 5,360 feet south of latitude 40°52′30″ and 3,900 feet east of longitude 75°45′. Section measured by J. D. Glaeser.

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 97D | Siltstone, medium-grained, grayish-red (5R4/2). Fissile. | 3.8 |
| 97C | Sandstone, medium- to coarse-grained, light-grayish-olive (10Y5/2). Conglomeratic. | 9.4 |
| 97B | Siltstone, medium- to coarse-grained, to very fine grained sandstone. Red and yellow brown, mixed and mottled. One quartzite pebble. | 5.6 |
| 97A | Sandstone, medium- to coarse-grained, light-olive-gray (5Y5/2). Conglomeratic. | 23.7 |
| 96 | Sandstone, fine- to very coarse grained, moderate-red (5R4/6) and grayish-red (5R4/2). Conglomeratic. | 35.2 |
| 95 | Sandstone, fine- to medium-grained, grayish-olive (10Y4/2). Crossbeds. Massive. Flaggy. | 25.7 |
| 94 | Siltstone, fine- to medium-grained. | 3.5 |
| 93 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2) to dark-grayish-red (5R3/2). Top truncated. | 7.0 |
| 92 | Siltstone, coarse-grained, grayish-red (5R4/2) to brownish-red (5YR4/1). | 8.0 |
| 91B | Siltstone, coarse-grained, to sandstone, very fine grained, medium-light-olive-gray (5Y5/1). Massive. | 2.0 |
| 91A | Siltstone, coarse-grained, light-olive-gray (5Y6/1) to light-brownish-gray (5YR6/1). Mottled, fracture fissility. | 2.0 |
| 90B | Siltstone, coarse-grained, grayish-red (5R4/2) to dark-yellowish-gray (5Y6/2). Colors mixed, fracture fissility. | 3.0 |
| 90A | Siltstone, fine- to coarse-grained, grayish-red (5R4/2) to dark-grayish-red (5R3/2). Base rippled. | 12.6 |
| 89 | Siltstone and medium- to very fine grained sandstone, pale-red (5R6/2) to dark-grayish-red (5R3/2). Massive. | 2.0 |
| 88 | Siltstone, coarse-grained, to sandstone, very fine grained, grayish-purple (5P4/2). Massive. | 3.0 |

| *Unit* | *Lithologic description* | *Thickness (feet)* |
|---|---|---|
| 87 | Siltstone, fine- to medium-grained, grayish-red (5R4/2), with incipient fissility. In mid-portion of bed, coarse-grained to very fine grained sandstone, light-grayish-red (5R5/2). Massive. | 0.61 |
| 86 | Sandstone, very fine grained, grayish-red-purple (5RP4/2). Massive. | 4.0 |
| 85 | Siltstone, fine- to coarse-grained, grades upward, grayish-red-purple (5RP4/2) to dusky-red (5R3/4). | 0.42 |
| 84 | Siltstone, coarse-grained, to sandstone, very fine grained, grayish-red (5RP4/2), and medium-grained sandstone, brownish-gray (5YR4/1) with load casts (lower 1 in.). | 1.33 |
| 83 | Siltstone, coarse-grained, grading up into fine-grained siltstone, fissile at top, grayish-red (5R4/2, 5R3/6). | 0.5 |
| 82 | Sandstone, fine- to medium-grained, light-grayish-purple (5P5/2) to brownish-red (5YR4/1). Massive. | 10.0 |
| 81 | Covered. | 3.33 |
| 80 | Shale and medium- to coarse-grained sandstone, in 50-50 mixture. Units 80 through 97D on east bank of Lehigh River. | 0.5 |
| 79 | Sandstone, medium-grained, grayish-red (10R4/2) to brownish-gray (5YR4/1). Red shale fragments. | 19.6 |
| 78B | Sandstone, medium- to very coarse grained, greenish-gray (5GY6/1) to dark-greenish-gray (5GY4/1). Green shale fragments. | 12.67 |
| 78A | Sandstone, medium- to very coarse grained, brownish-gray (5YR4/1). Red shale fragments. | 6.33 |
| 77 | Shale to siltstone, fine-grained, grayish-red (10R4/2). | 0.8 |
| 76 | Covered. | 24.5 |
| 75 | Shale to siltstone, fine-grained, dusky-red (5R3/4). | 3.0 |
| 74 | Siltstone, coarse-grained, to sandstone, very fine grained, grayish-red (5R4/2) to medium-light-brownish-gray (5YR5/1). | 0.58 |
| 73 | Siltstone, medium-grained, dark-grayish-red (5R3/2). | 0.5 |
| 72 | Sandstone, medium- to coarse-grained, brownish-gray (5YR4/1). Red shale fragments. | 8.0 |
| 71 | Siltstone, coarse- to medium-grained, dark-grayish-red (5R3/2) and grayish-red (5R4/2). | 0.8 |
| 70 | Sandstone, medium-grained, grayish-red (5R4/2). Flaggy. | 24.0 |
| 69 | Siltstone, fine-grained, dusky-red (5R3/4). Fracture cleavage dominant over bedding. | 23.0 |
| 68B | Siltstone, coarse- to medium- to fine-grained (upward), brownish-gray (5YR4/1). | 15.0 |
| 68A | Sandstone, medium-grained, becomes fine-grained, then very fine grained upward, grayish-red (5R4/2). | 51.0 |
| 67D | Siltstone, fine-grained, dark-greenish-gray (5GY4/1) to greenish-gray (5GY6/1). | 4.5 |
| 67C | Sandstone, medium-dark-greenish-gray (5GY5/1). | 4.0 |
| 67B | Siltstone, fine-grained, dark-greenish-gray (5GY4/1) to greenish-gray (5GY6/1). | 1.67 |
| 67A | Sandstone, medium-dark-greenish-gray (5GY5/1). | 1.25 |
| 66B | Siltstone, fine-grained, greenish-gray (5G6/1). Top interfingers with unit 67A. | 18.0 |
| 66A | Siltstone, fine-grained, grayish-red (5R4/2). | 3.0 |
| 65C | Siltstone, coarse-grained, grayish-red (5R4/2). Color mixed at top boundary. | 10.4 |
| 65B | Siltstone, medium- to coarse-grained, greenish-gray (5GY6/1) to medium-light-bluish-gray (5B6/1). | 8.4 |
| 65A | Sandstone, medium-grained, greenish-gray (5GY6/1). | 2.0 |
| 64B | Sandstone, medium- to coarse-grained, grayish-red (5R4/2) to medium-light-brownish-gray (5YR5/1). | 12.67 |
| 64A | Conglomerate. | 6.3 |
| 63 | Sandstone, very fine grained, upward to sandstone, fine-grained, moderate-red (5R5/4) to grayish-red (5R4/2). Top interfingers with unit 64A. | 21.0 |
| 62 | Sandstone, very fine to fine-grained, medium-light-gray (N6) to light-brownish-gray (5YR6/1). Top rippled. | 10.0 |
| 61 | Sandstone, very fine grained, grades upward to siltstone, coarse- to fine-grained, moderate-red (5R4/4) to pale-red (5R6/2). Ribbed, grooved surfaces. | 18.0 |
| 60 | Sandstone, very fine grained, grades upward to siltstone, coarse- to fine-grained, moderate-red (5R5/4) to light-grayish-red (5R5/2). Top 2 ft. is pockmarked. | 15.0 |
| 59 | Shale to fine-grained siltstone, dark-grayish-red (5R3/2). | 26.0 |
| 58 | Sandstone, very coarse grained, grades upward to very fine grained, medium-light gray (N6). | 19.5 |
| 57 | Siltstone, fine- to coarse-grained, grayish-red (5R4/2). | 23.6 |
| 56 | Siltstone, coarse-grained, to sandstone, fine- to very fine grained, grayish-red (5R4/2). | 15.0 |
| 55 | Sandstone, very fine grained, grades upward to siltstone, medium-grained, moderate-red (5R5/4) to grayish-red (5R4/2). | 8.0 |
| 54 | Shale to medium-grained siltstone, dusky-red (5R3/4) to dark-red (5R3/6). | 91.6 |
| 53 | Sandstone, medium- to fine-grained, medium-light-bluish-gray (5B6/1). Upper two-thirds is flaggy; lower third is massive. | 7.0 |
| 52B | Sandstone, coarse- to very coarse grained, greenish-gray (5G6/1). Conglomeratic. | 12.0 |
| 52A | Pebble conglomerate. Massive. | 3.0 |
| 51B | Siltstone, coarse-grained, light-grayish-red (5R5/2). | 0.5 |
| 51A | Siltstone, medium-grained, light-grayish-red (5R5/2). Increased clay content upward. | 13.5 |

| Unit | Lithologic description | Thickness (feet) |
|---|---|---|
| 50 | Siltstone, coarse-grained, to sandstone, very fine grained, greenish-gray (5GY6/1). Medium-bluish gray (5B5/1) to medium gray (N5) at base. Flaggy to massive (upward). | 38.3 |
| 49B | Shale, medium-gray (N5). | 3.0 |
| 49A | Siltstone, fine- to medium-grained, grayish-red (5R4/2). High clay content. | 15.0 |
| 48 | Siltstone, medium-grained, grayish-red (5R4/2) to medium-dark-greenish gray (5GY5/1). Colors mixed. | 6.0 |
| 47 | Sandstone, medium- to coarse-grained, medium-gray (N5). Top 1 inch grayish red (5R4/2). | 21.0 |
| 46B | Sandstone, coarse- to very coarse grained, pale-red (5R6/2). | 7.0 |
| 46A | Sandstone, medium- to coarse-grained, greenish-gray (5GY6/1). Conglomeratic. | 7.0 |
| 45 | Shale to fine-grained siltstone, dark-grayish-red (5R3/2). Massive, upward to fissile. Increase in clay content upward. Ripples in middle. | 33.4 |
| 44 | Sandstone, very fine grained, grayish-red (5R4/2). | 5.0 |
| 43 | Sandstone, fine- to medium-grained, grayish-red (5R4/2). Massive, flaggy. | 8.0 |
| 42 | Sandstone, coarse- to very coarse grained, light-grayish-red (5R5/2). Conglomeratic. Ripple-marked, white and pink quartz pebbles, red shale fragments. | 20.9 |
| 41 | Sandstone, medium-grained, pale-red (5R6/2). Massive upward to flaggy. | 19.0 |
| 40 | Shale and coarse-grained siltstone, grayish-red (5R4/2). Bedding indistinct. | 6.5 |
| 39 | Sandstone, fine-grained, grayish-red (5R4/2). Interference ripples in middle. Flaggy. | 7.0 |
| 38 | Sandstone, fine- to medium-grained, dark-grayish-red (5R5/2). Massive. | 7.5 |
| 37 | Sandstone, coarse- to very coarse grained, dark-grayish-red (5R5/2). Conglomeratic. | 50.8 |
|  | Total | 968.26 |

# SECTION 18

## POCONO AND SPECHTY KOPF FORMATIONS

Stratigraphic description of the Pocono and Spechty Kopf Formations at the recommended type locality, Jim Thorpe, Pennsylvania. The section occurs along a railroad cut on the east bank of the Lehigh River. The base is placed at the southwest edge of a stone retaining wall located a few yards northeast of a road which passes over the Lehigh Valley Railroad to the Jim Thorpe sewage treatment plant. The section parallels the railroad for over 2,500 feet and ends along an abandoned railroad spur adjacent to a supermarket parking lot. Base of section is approximately at 40°51′36″ N/75° 44′06″ W. Section measured by W. D. Sevon.

| Unit | Lithologic description | Thickness (in feet) |
|---|---|---|
| *Mauch Chunk Formation*<br>(93 feet thick; incomplete) |  |  |
| 260 | Siltstone, very coarse grained, grayish-red (5R4/2), massive; breaks down into ⅛- to ¼-in.-thick irregular plates; upper part is covered. | 2.5 |
| 259 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2), massive; hackly weathered pieces; upper contact is gradational. | 0.75 |
| 258 | Siltstone, fine-to medium-grained, olive-gray (5Y4/1), mottled with grayish red (5R4/2) to dusky red (5R3/4) along joints and some bedding planes; irregularly hackly weathered plates, dominantly red at 2½ to 3 ft.; gradational upper contact. | 8.0 |
| 257 | Siltstone, fine-grained, olive-gray (5Y5/2) with occasional trace of red; hackly weathered pieces; weathered color slightly lighter green; gradational upper contact. | 1.83 |
| 256 | Siltstone, fine-grained, greenish-gray (5GY5/1), massive; hackly weathered pieces; weathered color slightly lighter green; gradational upper contact. | 1.42 |
| 255 | Siltstone, coarse-grained, between moderate-yellowish-brown (10YR5/4) and dusky-yellow (5Y6/4), massive with some suggestion of bedding planes; hackly weathered pieces; gradational upper contact. | 6.0 |
| 254 | Sandstone, very fine grained, between moderate-yellowish-brown (10YR5/4) and dusky-yellow (5Y6/4), massive, structureless, well indurated; basal 1 to 1½ ft. is fine-grained sandstone; well sorted quartz sandstone; breaks down to hackly blocks; abundant fine-grained mica flakes; gradational upper contact, uppermost Pocono sandstone lithology. | 11.0 |
| 253 | Sandstone, medium-grained, near yellowish-gray (5Y7/2); bedding not well defined but some beds 1 to 6 in. thick; well-sorted subangular quartz sandstone with some clay matrix (decomposed feldspar?); small amount of very fine to fine-grained muscovite flakes and 1 percent medium-grained biotite flakes; gradational upper contact. | 7.5 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 252 | Sandstone, massive unit with color near yellowish-gray (5Y7/2); internal subdivision is:<br>Seven ft. 6 in.: sandstone, medium-grained; quartz sandstone, with occasional pebbles up to ¼ in. in diameter scattered at random; some of sand may be coarse grained.<br>One-fourth to 2 in.: pebble zone; rounded quartz pebbles along well-defined plane; 1-in. maximum, ¼-in. average.<br>Ten in.: sandstone, fine- to medium-grained; quartz sand; no pebbles; sharp upper contact. | 8.33 |
| 251 | Covered interval. | 1.5 |
| 250 | Siltstone, medium- to coarse-grained, near grayish-orange (10YR7/4), massive; breaks into small hackly pieces. | 2.17 |
| 249 | Siltstone, very coarse grained, near grayish-orange (10YR7/4); upper contact is sharp bedding plane. | 0.17 |
| 248 | Sandstone, very fine to fine-grained, light-olive-gray (5Y6/1) with slight reddish-brown appearance; quartz sandstone; some muscovite flakes up to very coarse grained; some dark grains; upper contact sharp bedding plane. | 0.42 |
| 247 | Siltstone, very coarse grained, near grayish-orange (10YR7/4); irregular sharp upper contact. | 0.75 |
| 246 | Sandstone, very fine to fine-grained, light-olive-gray (5Y6/1) with slight red appearance; some muscovite flakes up to very coarse grained; some dark grains; sharp upper contact. | 0.33 |
| 245 | Sandstone, very fine grained with very coarse grained silt, light-olive-gray (5Y6/1) with red appearance, well-bedded with ⅛- to ¼-in.-thick beds; some fine-grained mica flakes; disintegrates easily; sharp upper contact. | 2.0 |
| 244 | Sandstone, fine-grained, light-olive-gray (5Y6/1) with slight red appearance, massive, well-indurated; joints normal to bedding; mica flakes up to medium grained; sharp upper contact. | 2.0 |
| 243 | Sandstone, as unit 245. | 0.83 |
| 242 | Sandstone, fine-grained (basal 3 ft. of unit is gradational from fine to medium grained), light-olive-gray (5Y6/1) with slight red appearance, massive, well-indurated; mica flakes up to medium grained; sharp upper contact; basal surface is knobbly and knobs may be small load casts. | 6.5 |
| 241 | Siltstone, fine-grained, greenish-gray (5GY6/1 to 5G6/1); prominent cleavage; weak zone; disintegrates into hackly pieces; sharp upper contact. | 2.58 |
| 240 | Siltstone, fine-grained, grayish-red (5R4/2); prominent cleavage; disintegrates into hackly pieces; zone 1½ to 2 ft. above the base nearly quartzitic; gradational upper contact. | 12.0 |
| 239 | Siltstone, coarse-grained, grayish-red (5R4/2) to dusky-red (5R3/4); very fine grained mica flakes; numerous bedding planes; disintegrates into hackly plates which parallel bedding; gradational upper contact. | 12.42 |
| 238 | Sandstone, very fine grained, gray-red-purple (5RP4/2), very hard and well indurated; some mica flakes; some mottling in lower half; abrupt gradational upper contact. | 2.0 |

*Pocono Formation*
(821.16 feet thick; complete)

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 237 | Sandstone, fine-grained, near pale-brown (5YR5/2) or pale-yellowish-brown (10YR4/2) with slightly gray appearance, quartzitic, massive; some conchoidal parting; some mica flakes; gradational upper contact. | 19.5 |
| 236 | Covered interval. Top of covered interval is at north edge of stone foundation structure which probably upheld a water tank at one time. Base of the covered interval is at the top of the last well-exposed sandstone to the south of the stone foundation. | 266.0 |
| 235 | Sandstone, medium-grained, light-gray (N7), quartzitic, massive; some small spots of clay; over 95 percent quartz; few dark grains; sandstone may be coarse grained in part. | 6.5 |
| 234 | Sandstone, medium-grained, light-gray (N7), quartzitic; contains medium-gray (N4) shale chips up to 1½ in. in diameter and ⅛ in. thick and rounded quartz pebbles to ½ in. in diameter; some coarse- to very coarse grained muscovite flakes; shale chips may be a disrupted clay layer; gradational upper contact (part of same unit as 235). | 0.17 |
| 233 | Sandstone, medium-grained, light-gray (N7), quartzitic; coarse- to very coarse grained muscovite flakes abundant; possible planar crossbed at top; plant fossil molds on some surfaces; small ¼- to ½-in. pyritic nodules; sharp upper contact. | 8.5 |
| 232 | Sandstone, as unit 233, but with definite beds ½ to 1 in. thick. | 0.42 |
| 231 | Sandstone, as unit 233, but massive. | 1.33 |
| 230 | Sandstone, fine-grained, light-gray (N7); contains scattered coarser sand grains and rounded quartz pebbles up to ½ in. in diameter and medium-gray (N4) shale chips up to 1½ in. in diameter. Sharp upper contact. | 0.5 |
| 229 | Shale, light-olive-gray (5Y5/2), irregular, slickensided, laterally discontinuous; sharp contacts. | 0.17 |
| 228 | Sandstone, as unit 230, but with more shale chips; sharp upper contact. | 0.08 |
| 227 | Sandstone, as unit 233; rapidly gradational upper contact. | 7.0 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 226 | Sandstone, as unit 230, but with only rare quartz pebbles; lateral variation in thickness from 3 to 10 in.; sharp upper contact. | 0.83 |
| 225 | Sandstone, as unit 233; sharp upper contact. | 10.0 |
| 224 | Sandstone, medium- to very coarse grained, angular to subrounded quartz grains with some pebbles up to ¼ in. in diameter set in a matrix of hard black clayey material; some mica flakes; some dark-gray (N3) shale chips; some irregular bedding planes; sharp upper contact. | 0.25 |
| 223 | Sandstone, medium-grained, light-gray (N7), quartzitic, massive; some hairline dark-gray (N3) shale planes and rare shale chips parallel to bedding; numerous rounded quartz pebbles up to ¼ in. in diameter in basal 2 ft.; sharp upper contact. | 12.0 |
| 222 | Sandstone, medium-grained, light-gray (N7), quartzitic, massive; scattered planes with shale chips; gradational upper contact. | 27.0 |
| 221 | Sandstone, medium- to very coarse grained, light-gray (N7), quartzitic; scattered subangular quartz pebbles up to ¼ in. in diameter, gradational upper contact. | 0.83 |
| 220 | Sandstone, as unit 222, but partially covered; gradational upper contact. | 10.0 |
| 219 | Conglomerate, pebbles up to ½ in. in diameter in matrix of medium- to very coarse grained quartz sand; some blue to dark-gray (N3) shale chips; no bedding; poorly sorted; sharp upper contact. | 3.0 |
| 218 | Sandstone, coarse-grained grading to medium-grained in upper third, light-gray (N7), quartzitic; may be crossbedded; breaks into slabs 2 to 3 in. thick; sharp upper contact. | 16.0 |
| 217 | Conglomerate, ⅛- to ¼-in. pebbles compose over 50 percent of conglomerate; some matrix is fine- to medium-grained sand, massive, quartzitic; no bedding but some parting parallel to bedding; orientation of long pebble axes parallel to bedding; gradational upper contact. | 4.5 |
| 216 | Sandstone, medium-grained, light-gray (N7), quartzitic, partially covered in lower 5 feet; sharp upper contact. | 13.0 |
| 215 | Sandstone, medium-grained, light-gray (N7), quartzitic, massive; upper surface has abundant medium-gray (N5) shale chips up to 5 in. in diameter but generally 2 in. or less in diameter; random quartz pebbles up to ½ in. in diameter; rare shale chips throughout and a plane of shale chips 3 ft. 6 in. above base; sharp upper contact. | 16.5 |
| 214 | Conglomerate, rounded quartz pebbles up to ¾ in. in diameter which average ¼ to ½ in. in diameter and compose 25 to 50 percent of the conglomerate; matrix is coarse- to very coarse grained quartz sand; scattered shale chips up to 3 in. in diameter; sharp upper contact. | 0.83 |
| 213 | Sandstone, medium- to coarse-grained, light-gray (N7), quartzitic, massive; few scattered rounded quartz pebbles up to ¼ in. in diameter; sharp upper contact. | 2.5 |
| 212 | Conglomerate, rounded quartz pebbles averaging ¼ in. in diameter compose 25 percent of conglomerate; medium-grained quartz matrix; light gray (N7) to very light gray (N8); quartzitic; no bedding; poor sorting; gradational upper contact. | 2.0 |
| 211 | Sandstone, medium-grained, medium-light-gray (N6), quartzitic; some scattered very coarse grained quartz grains; bedding indicated by very fine dark lines (mineral concentrate?); suggestion of large crossbed; occasional shale chips up to 6 in. in diameter in lower half and a nearly continuous shale-chip horizon at 7 ft. 6 in. above base; sharp upper contact. | 14.5 |
| 210 | Conglomerate, light-gray (N7) stained reddish brown (10R3/4); quartz pebbles up to ½ in. in diameter and averaging ¼ in. in diameter; matrix is medium-grained quartz sand; quartzitic; no bedding evident; poor sorting; sharp upper contact. | 3.5 |
| 209 | Sandstone, fine- to medium-grained, light-gray (N7), quartzitic; some scattered rounded quartz pebbles up to ¼ in. in diameter; long crossbeds 1 to 2 in. thick taper to zero thickness; upper contact sharp and irregular. | 2.5 |
| 208 | Sandstone, medium-grained with up to 10 percent rounded quartz pebbles up to ¼ in. in diameter randomly scattered; quartzitic; sharp upper contact. | 0.58 |
| 207 | Sandstone, medium-grained, light-gray (N7), massive, quartzitic; some scattered quartz pebbles up to ¼ in. in diameter; sharp and irregular upper contact. | 3.0 |
| 206 | Sandstone, coarse- to very coarse grained, light-gray (N7), massive, quartzitic; up to 10 percent quartz pebbles up to ¼ in. in diameter; sharp upper contact. | 4.75 |
| 205 | Sandstone, fine-grained, light-gray (N7); brown weathered color; massive; may be laterally discontinuous; sharp upper contact. | 0.83 |
| 204 | Conglomerate, over 25 percent pebbles averaging ¼ in. in diameter with maximum ½-in. diameter; medium- to coarse-grained sand matrix; light gray (N7); quartzitic; rounded to subangular pebbles; sharp upper contact. | 3.5 |
| 203 | Sandstone, medium- to coarse-grained, very light gray (N8), quartzitic; some bedding planes; sharp upper contact. | 8.0 |
| 202 | Conglomerate, as unit 204. | 0.42 |
| 201 | Sandstone, as unit 203. | 2.5 |
| 200 | Sandstone, medium- to coarse-grained, light-gray (N7), quartzitic; up to 10 percent pebbles up to ¼ in. in diameter; some medium-dark-gray (N4) shale chips up to 2 in. in diameter; some irregular planes present; upper half mainly covered; gradational upper contact. | 20.0 |
| 199 | Conglomerate, pebbles averaging ¼ to ½ in. in diameter with maximum of 1 in.; coarse- to very coarse grained sandstone matrix; some shale chips up to 5 in. in diameter, massive; no bedding, poorly sorted; sharp upper contact. | 2.0 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 198 | Sandstone, medium- to coarse-grained, light-gray (N7), quartzitic; gradational upper contact. | 2.0 |
| 197 | Conglomerate, as unit 199; sharp upper contact. | 2.0 |
| 196 | Sandstone, as unit 198, with some crossbed planes at base; sharp upper contact. | 1.33 |
| 195 | Conglomerate, as unit 199; gradational upper contact. | 2.0 |
| 194 | Sandstone, very fine to fine-grained, medium-dark-gray (N4), moderately well indurated; some mica flakes; crossbeds with 1/16- to 1/8-in.-thick beds; sharp upper contact. | 2.0 |
| 193 | Sandstone, fine- to medium-grained, light-gray (N7), massive, quartzitic; plant fossil molds on bedding planes; crossbed topsets; gradational upper contact. | 4.0 |
| 192 | Conglomerate, pebble content varies from 15 to 50 percent; pebbles average ¼ in. in diameter with maximum ½ in.; rounded to subangular pebbles; fine- to medium-grained sand matrix; quartzitic; sharp upper contact. | 4.5 |
| 191 | Sandstone, fine- to medium-grained, light-gray (N7), quartzitic, thinly bedded in part; gradational upper contact. | 10.0 |
| 190 | Conglomerate, pebbles averaging ½ in. in diameter with maximum 2½ in.; pebbles are rounded quartz; medium- to coarse-grained sand matrix; quartzitic; pebbles are partially aligned with axes parallel to bedding and defined pebble beds; laterally irregular in thickness and in places includes part of the overlying bed; massive; sharp upper contact. | 4.0 |
| 189 | Sandstone, as unit 191; sharp upper contact. | 0.83 |
| 188 | Conglomerate, rounded quartz pebbles up to 2½ in. in diameter with average ½ to 1 in.; medium- to coarse-grained sandstone matrix; massive; structureless; irregularly defined sandstone beds occur in the upper 15 feet; sharp upper contact. | 50.0 |
| 187 | Sandstone, fine-grained, medium-light-gray (N5), massive, quartzitic; some shale chips up to 4 in. in diameter randomly scattered; fossil plant molds on some bedding planes; structureless, very uniform appearance; sharp irregular upper contact. | 28.0 |
| 186 | Sandstone, fine-grained, medium-light-gray (N5), massive; quartzitic; some shale chips which are sufficiently abundant, well oriented, and large to suggest a disruption of an original clay-shale deposit; shale chips lacking in central 1 in.; sharp upper contact. | 23.5 |
| 185 | Sandstone, as unit 187, with rare quartz pebbles up to ¼ in. in diameter; sharp upper contact. | 11.0 |
| 184 | Conglomerate, light-gray (N7); pebbles up to ½ in. in diameter and average ¼ in.; medium-grained sandstone matrix is 25 to 50 percent of the whole; quartzitic; sharp upper contact. | 1.0 |
| 183 | Sandstone, fine-grained, medium-light-gray (N6); clayey matrix; very coarse grained mica flakes; massive but breaks into beds; gradational upper contact. | 7.0 |
| 182 | Shale, gray-black (N2) to black (N1), clayey, thin-bedded, very crushed and distorted; upper contact obscure but apparently sharp. | 5.0 |
| 181 | Sandstone, medium-grained, very light gray (N8), quartzitic, laterally has conglomerate zones up to 6 in. thick; lower 2 ft. is crossbedded and rests on an irregular surface; sharp upper contact. | 8.0 |
| 180 | Conglomerate, 25 to 50 percent pebbles averaging ½ to 1 in. in diameter; some elongate pebbles are up to 2 in. long while others are more nearly spherical and near 1 in. in diameter; pebbles are rounded to subrounded; medium-grained sand matrix; massive; quartzitic; structureless; some cavities filled with quartz crystals up to ¾ in. long and ¼ in. in diameter; sharp irregular upper contact. | 21.5 |
| 179 | Sandstone, medium-grained, very light gray (N8), quartzitic, massive, structureless; some red stain in parts; well sorted; sharp irregular upper contact. | 5.5 |
| 178 | Sandstone, very coarse grained, very light gray (N8); fair sorting; sharp upper contact. | 2.0 |
| 177 | Sandstone, as unit 179; sharp upper contact. | 0.67 |
| 176 | Conglomerate, over 50 percent pebbles averaging ¼ to ½ in. in diameter with maximum 1-in. diameter, massive, structureless, quartzitic; sharp irregular upper contact. | 7.0 |
| 175 | Siltstone, medium- to coarse-grained, brown; some medium-grained quartz grains; discontinuous; irregular upper contact. | 0.17 |
| 174 | Conglomerate, as unit 176; irregular thickness varies from 6 to 12 in.; sharp upper contact. | 1.0 |
| 173 | Sandstone, medium-grained, medium-gray (N5), moderately indurated; dark-gray (N3) shale chips up to 2½ in. in diameter with average less than lower 2 in.; has 15 to 25 percent quartz pebbles ¼ to ½ in. in diameter; sharp upper contact. | 0.5 |
| 172 | Sandstone, medium-grained, medium-gray (N5), moderately well indurated; may intertongue laterally with conglomerate; gradational upper contact. | 2.25 |
| 171 | Sandstone, coarse-grained, light-gray (N7), moderately well indurated to quartzitic; some scattered ¼-in.-diameter quartz pebbles; some red iron stain; sharp upper contact. | 5.0 |
| 170 | Shale, black; thin weak zone of fine-grained siltstone at base grades up into shale with intermixed medium-grained sandstone stringers and zones of pure clay shale; some suggestion of plant impressions; unit is crushed and weathered; underlying sandstone surface has holes which may represent areas from which shale has been weathered; sharp upper contact. | 6.0 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 169 | Sandstone, medium-grained, quartz grains set in fine-grained matrix, medium-dark-gray (N4) to dark-gray (N3), quartzitic; occasional shale chips; sharp upper contact with irregular holes on upper surface probably representing holes from which overlying shale was weathered. | 7.0 |
| 168 | Siltstone, medium- to coarse-grained, dark-gray (N3), massive, structureless; impression of log at least 7 ft. long on bedding plane; gradational upper contact; thickness varies from 4 to 9 in. | 0.75 |
| 167 | Sandstone, medium-grained, light-gray (N7), massive, quartzitic; sharp upper contact. | 17.5 |
| 166 | Sandstone, medium- to coarse-grained, light-gray (N7), with 10 to 20 percent quartz pebbles averaging ⅛ to ¼ in. in diameter, quartzitic; some intermixed siltstone; sharp irregular upper contact. | 2.0 |
| 165 | Sandstone, as unit 167, with crossbedding shown by dark lines on fresh surfaces; overall appearance is massive; sharp irregular upper contact. | 9.0 |
| 164 | Siltstone, medium-grained, dark-gray (N3), ⅛- to ¼-in.-thick beds; conchoidal weathering masses; discontinuous sandstone layer 2 ft. above base varies from 0 to 2 ft. thick; sharp irregular upper contact. | 15.0 |
| 163 | Sandstone, medium-grained, medium-dark-gray (N4) to medium-gray (N5), quartzitic; scattered rounded quartz pebbles up to ¼ in. in diameter in basal 2 in.; coarse-grained mica flakes in upper 10 ft.; structureless for most part but some bedding in upper 10 ft.; sharp irregular upper contact. | 32.0 |
| 162 | Shale, black; 1/16- to ⅛-in. beds; sharp upper contact. | 1.67 |
| 161 | Sandstone, medium-grained, light-gray (N7), quartzitic; grades from very coarse grained sandstone at base to medium-grained sandstone 2 ft. above base; top of 6-in.-thick zone of mixed sandstone and shale at 9 in. below top; sharp upper contact. | 6.0 |
| 160 | Conglomerate, 25 to 50 percent rounded quartz pebbles averaging ¼ to ½ in. in diameter with maximum 2 in.; medium- to coarse-grained sand matrix; 7 ft. above base is discontinuous zone of siltstone and pebble-free sandstone; sharp upper contact. | 17.0 |
| *Spechty Kopf Formation*<br>(547.83 feet thick; complete) | | |
| 159 | Siltstone, fine-grained, light-olive-gray (5Y5/2); basal 6 in. fines upward from coarse-grained siltstone; hackly breakup; irregular upper contact. | 4.0 |
| 158 | Sandstone, medium-grained, medium-gray (N5), poorly sorted, quartzitic; sharp upper contact. | 0.58 |
| 157 | Sandstone, very fine grained, light-gray (N7), quartzitic; ¼- to 1-in. beds; sharp upper contact. | 1.83 |
| 156 | Sandstone, as unit 158, but with basal 1 in. containing rounded ¼-in.-diameter quartz pebbles; sharp upper contact. | 1.17 |
| 155 | Sandstone, as unit 157; sharp upper contact. | 1.5 |
| 154 | Sandstone, as unit 158, but with some ¼-in. quartz pebbles scattered throughout; sharp upper contact. | 11.0 |
| 153 | Siltstone, coarse-grained, between grayish-orange (10YR7/4) and moderate-yellowish-brown (10YR5/4), massive, structureless; hackly weathering; sharp upper contact. | 8.0 |
| 152 | Sandstone, very fine grained, light-olive-gray (5Y5/2); fine- to medium-grained mica flakes abundant; sharp upper contact. | 3.0 |
| 151 | Siltstone, as unit 153; sharp upper contact. | 2.5 |
| 150 | Sandstone, as unit 152; sharp upper contact. | 1.33 |
| 149 | Siltstone, as unit 153; sharp upper contact. | 1.67 |
| 148 | Sandstone, as unit 152; sharp upper contact. | 4.5 |
| 147 | Siltstone, as unit 153; sharp upper contact. | 31.0 |
| 146 | Sandstone, fine-grained, medium-gray (N5), quartzitic; definite beds; sharp upper contact. | 1.17 |
| 145 | Siltstone, as unit 153; basal 1½ ft. may be slightly coarser than rest; sharp upper contact. | 6.5 |
| 144 | Siltstone, coarse-grained, medium-dark-gray (N4); massive at top, 2- to 3-in. beds at base; gradational upper contact. | 2.0 |
| 143 | Sandstone, very fine grained, medium-dark-gray (N4), quartzitic, bedded with some crossbedding shown by dark lines; sharp upper contact. | 1.0 |
| 142 | Siltstone, medium-to coarse-grained, medium-gray (N4); may be laterally discontinuous; medium-grained mica flakes; shaly nature; sharp upper contact. | 0.42 |
| 141 | Sandstone, fine-grained, medium-gray (N5), quartzitic, massive; may be medium-grained in lower part; sharp upper contact. | 21.83 |
| 140 | Sandstone, fine-grained, medium-dark-gray (N4) to medium-gray (N5); abundant coarse- to very coarse grained mica flakes on bedding planes; large thin tabular crossbed sheets ½ to 1 in. thick with low inclinations; very well indurated; sharp upper contact. | 4.0 |
| 139 | Sandstone, fine- to medium-grained, medium-dark-gray (N4), quartzitic, massive; crossbed sheets 2 to 6 in. thick; sharp bedding planes; coarse-grained mica flakes on some bedding planes; sharp upper contact. | 15.0 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 138 | Shale, mixed dark-gray (N3) clay shale and coarse-grained sandstone; shale seems to occur in thin layers; sandstone is moderately to poorly indurated; sharp upper contact. | 1.17 |
| 137 | Sandstone, fine-grained becoming medium-grained in upper 6 in., medium-dark-gray (N4), quartzitic; sharp upper contact. | 2.17 |
| 136 | Siltstone, coarse- to very coarse grained, medium-dark-gray (N4); mica flakes; laterally discontinuous; thin bedded and platy; sharp upper contact. | 0.08 |
| 135 | Sandstone, as unit 137; sharp upper contact. | 2.42 |
| 134 | Siltstone, fine- to medium-grained, near greenish-gray (5GY6/1), stained with metallic color near grayish blue (5PB4/2); weathered surface is knobbly and iron stained; very disrupted appearance, sharp upper contact. | 2.0 |
| 133 | Sandstone, very fine grained, medium-dark-gray (N4), well-indurated; abundant medium-grained mica flakes; upper 6 in. has ½- to 1-in.-thick beds, lower part is massive; sharp upper contact. | 2.0 |
| 132 | Siltstone, coarse-grained, medium-dark-gray (N4), hard, brittle, very homogeneous; sharp upper contact. | 0.42 |
| 131 | Sandstone, medium-grained, partly fine-grained in middle third, medium-gray (N5), quartzitic; large tabular crossbed sheets; sharp upper contact. | 17.0 |
| 130 | Shale, black (N1), platy, laterally discontinuous, very disrupted; irregular sharp upper contact. | 0.17 |
| 129 | Sandstone, very fine grained, medium-dark-gray (N4), quartzitic, massive; very faint suggestion of bedding; some bedding planes marked by very coarse grained mica flakes; irregular upper contact. | 6.5 |
| 128 | Siltstone, coarse-grained, dark-gray (N3); hackly breakup; some interlaminated fine-grained sandstone but mainly siltstone; irregular sharp upper contact. | 1.0 |
| 127 | Sandstone, medium-grained, medium-dark-gray (N4) to medium-gray (N5), quartzitic, massive; few scattered ⅛- to ¼-in. shale chips in upper 6 in.; some breakup into 6-in.-thick beds; some suggestion of crossbedding in middle third; irregular sharp upper contact. | 19.5 |
| 126 | Sandstone, very fine grained, dark-gray (N3); 1- to 2-in. beds; quartzitic; sharp upper contact. | 3.17 |
| 125 | Sandstone-shale, zone of mixed medium-grained sandstone and black shale in thin layers and shale chips; irregular and disrupted zone; sharp upper contact. | 0.67 |
| 124 | Sandstone, fine- to medium-grained, medium-dark-gray (N4), quartzitic; ⅛- to ¼-in. shale chips scattered throughout along bedding planes; sharp upper contact. | 0.33 |
| 123 | Siltstone, coarse- to very coarse grained, dark-gray (N3), laminated; mica flakes; hard; sharp upper contact. | 0.17 |
| 122 | Sandstone, as unit 124; sharp upper contact. | 0.12 |
| 121 | Siltstone, as unit 123; sharp upper contact. | 0.75 |
| 120 | Sandstone, fine-grained, medium-dark-gray (N4), well-indurated; some coarse-grained mica flakes on bedding planes; sharp upper contact. | 1.67 |
| 119 | Sandstone-shale, as unit 125; sharp upper contact. | 0.83 |
| 118 | Sandstone, as unit 120; sharp upper contact. | 8.0 |
| 117 | Sandstone, medium-grained, medium-dark-gray (N4), massive, quartzitic; upper 1 in. is coarse grained with ⅛- to ¼-in. shale chips; sharp upper contact. | 3.33 |
| 116 | Siltstone, medium-grained, medium-dark-gray (N4), hard, homogeneous, slightly brittle; sharp hackly breakup pieces; sharp upper contact. | 4.0 |
| 115 | Sandstone, medium-grained, medium-light-gray (N6), moderately well indurated; abundant coarse-grained mica flakes; hairline dark laminae indicate bedding; sharp upper contact. | 2.0 |
| 114 | Siltstone, fine- to medium-grained, medium-gray (N5) to light-olive-gray (5Y5/2), platy, disrupted; upper contact gradational. | 0.67 |
| 113 | Sandstone, fine-grained, medium-gray (N5), well-indurated, bedded, gradational upper contact. | 0.58 |
| 112 | Siltstone, very coarse grained, medium-dark-gray (N4), bedded; some fine-grained mica flakes; gradational upper contact. | 1.75 |
| 111 | Sandstone, medium-grained, medium-gray (N5), quartzitic, massive; some medium-grained mica flakes; sharp upper contact. | 10.0 |
| 110 | Siltstone, coarse- to very coarse grained, medium-dark-gray (N4), massive; breaks into ⅛- to ¼-in.-thick beds; slightly brittle; sharp upper contact. | 4.0 |
| 109 | Sandstone, very fine grained, medium-dark-gray (N4), quartzitic, massive; some bedding shown by hairline dark lines; sharp upper contact. | 18.0 |
| 108 | Siltstone, fine-grained, medium-dark-gray (N4), massive, quartzitic; becomes coarser upward in upper half and is coarse grained in upper 1 in.; sharp upper contact. | 8.0 |
| 107 | Fault plane; crush zone of dark siltstone. | 0.25 |
| 106 | Sandstone, medium- to coarse-grained, medium-light-gray (N6), quartzitic; faulted surface is very irregular; thickness may be less than indicated since laterally there is some wedging of this unit and considerable irregularity. | 6.0 |
| 105 | Siltstone, very coarse grained, medium-dark-gray (N4), laminated; dark color bands show laminae less than 1 mm apart; some 2- to 6-in.-thick medium- to coarse-grained sandstone layers along lateral extension may be faulted into position; sharp upper contact. | 2.0 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 104 | Sandstone, fine- to medium-grained, medium-dark-gray (N5), quartzitic, massive; lower surface is irregular with possible load casts; sharp upper contact. | 3.5 |
| 103 | Siltstone, medium-grained, medium-dark-gray (N4), massive; sharp upper contact. | 2.0 |
| 102 | Sandstone, medium-grained, partly coarse-grained, medium-gray (N5), quartzitic; scattered shale chips; lateral variation in thickness (1 to 4 in.); sharp upper contact. | 0.33 |
| 101 | Sandstone, medium-grained, medium-gray (N5), quartzitic, massive; gradational upper contact. | 8.75 |
| 100 | Sandstone, medium-grained, medium-dark-gray (N4), quartzitic; shale chips up to ¼ in. in diameter mixed irregularly throughout; sharp upper contact. | 0.42 |
| 99 | Sandstone, as unit 101; upper contact gradational. | 0.83 |
| 98 | Sandstone, as unit 100; gradational upper contact. | 0.33 |
| 97 | Sandstone, fine-grained, medium-dark-gray (N4), quartzitic; gradational upper contact. | 1.33 |
| 96 | Sandstone, coarse- to very coarse grained; rare quartz pebbles to ⅛ in. in diameter; some shale chips up to ¼ in.; gradational upper contact. | 0.33 |
| 95 | Sandstone, as unit 97, with laminae indicated by color lines; gradational upper contact. | 0.42 |
| 94 | Sandstone, as unit 96, with numerous shale chips up to ¼ in. in diameter which weather with iron stain; gradational upper contact. | 0.42 |
| 93 | Sandstone, very fine grained, medium-dark-gray (N4), quartzitic; gradational upper contact. | 0.42 |
| 92 | Sandstone, very fine grained, medium-dark-gray (N4); rounded quartz pebbles up to ¾ in. in diameter and rounded dark-gray (N3) shale pebbles with iron-stained rims up to 1 in. in diameter; gradational upper contact. | 0.25 |
| 91 | Sandstone, as unit 93; gradational upper contact. | 0.17 |
| 90 | Sandstone, as unit 92: laterally this unit and unit 92 may become one with no central sandstone; weathered shale chips leave moderate-brown pits on rock; gradational upper contact. | 0.67 |
| 89 | Sandstone, fine-grained, medium-gray (N5), quartzitic; 1- to 6-in.-thick beds; load casts on lower surface; gradational upper contact. | 7.5 |
| 88 | Siltstone, medium-grained, medium-dark-gray (N4), massive; prominent cleavage; gradational upper contact. | 1.0 |
| 87 | Siltstone, very fine grained, medium-dark-gray (N4), quartzitic, massive; several 1½-in.-diameter weathered pyrite nodules; gradational upper contact. | 1.33 |
| 86 | Siltstone, as unit 88; sharp upper contact. | 4.0 |
| 85 | Sandstone, as unit 87; sharp upper contact. | 0.42 |
| 84 | Siltstone, as unit 88; this unit grades upward from underlying unit and although the contact is distinctive it is really one continuous graded bed; sharp upper contact. | 0.5 |
| 83 | Sandstone, as unit 87; gradational upper contact. | 0.67 |
| 82 | Sandstone, as unit 87, with siltstone in upper ½ in.; sharp upper contact. | 0.21 |
| 81 | Sandstone, as unit 82; sharp upper contact. | 0.42 |
| 80 | Sandstone, as unit 87; sharp upper contact. | 0.75 |
| 79 | Sandstone, as unit 87, with upper 1 in. siltstone as unit 88; sharp upper contact. | 0.25 |
| 78 | Sandstone, as unit 79; sharp upper contact. | 0.42 |
| 77 | Sandstone, as unit 79; upper ½ in. siltstone; sharp upper contact. | 0.29 |
| 76 | Sandstone, as unit 77; sharp upper contact. | 0.37 |
| 75 | Sandstone, as unit 77; sharp upper contact. | 0.33 |
| 74 | Sandstone and siltstone, sandstone (as unit 87) 1½-in. thick grades up into siltstone (as unit 88); sharp upper contact. | 0.37 |
| 73 | Siltstone, as unit 88, seems nearly gradational from lower unit and into upper unit and is typical of the siltstone beds in this part of the section. Basal contact is the sharpest in appearance and the siltstone is marked by acute-angle cleavage; sharp upper contact. | 0.17 |
| 72 | Sandstone, as unit 87; sharp upper contact. | 1.67 |
| 71 | Siltstone, as unit 88; sharp upper contact. | 0.83 |
| 70 | Sandstone, as unit 87; sharp upper contact. | 0.67 |
| 69 | Siltstone, as unit 88; sharp upper contact. | 0.17 |
| 68 | Sandstone, as unit 87; sharp upper contact. | 1.58 |
| 67 | Siltstone, as unit 88; sharp upper contact. | 0.08 |
| 66 | Sandstone, as unit 87; gradational upper contact. | 0.58 |
| 65 | Siltstone, as unit 88; parting of siltstone; sharp contacts. | 0.10 |
| 64 | Sandstone, as unit 87; sharp upper contact. | 1.33 |
| 63 | Siltstone, as unit 88; parting of siltstone which varies in thickness laterally; sharp contacts. | 0.02 |
| 62 | Sandstone, as unit 87; sharp upper contact. | 0.92 |
| 61 | Siltstone, as unit 88; parting of siltstone which laterally thickens and thins; sharp contacts. | 0.08 |
| 60 | Sandstone, as unit 87; sharp contacts. | 2.0 |
| 59 | Siltstone, as unit 88; sharp contacts. | 0.04 |
| 58 | Sandstone, fine-grained, medium-dark-gray (N4), quartzitic, structureless; sharp upper contact. | 3.08 |
| 57 | Siltstone, fine- to medium-grained, dark-gray (N3), platy; sharp upper contact, gradational lower contact. | 0.08 |
| 56 | Sandstone, as unit 58; gradational upper contact. | 1.83 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 55 | Siltstone, as unit 57; sharp upper contact. | 0.17 |
| 54 | Sandstone, as unit 58; gradational upper contact. | 0.42 |
| 53 | Siltstone, as unit 57; sharp upper contact. | 0.21 |
| 52 | Sandstone, as unit 58; sharp upper contact. | 5.58 |
| 51 | Sandstone, medium- to coarse-grained, light-gray (N7); shale chips up to ¼ in. in diameter; moderate induration; sharp upper contact. | 0.33 |
| 50 | Sandstone, as unit 58; massive in appearance but breaks into beds 1 in. to 2 ft. thick; uniform texture; sharp upper contact. | 24.0 |
| 49 | Covered interval, behind concrete retaining wall; no crop above wall; probably same as unit 50 or possibly some of unit 50 and unit 48. | 10.0 |
| 48 | Sandstone, medium-grained, white, very pure quartz, extremely hard; bedding shown by sharply defined partings which separate beds varying from 1 to 10 in. thick with an average thickness of about 5 in. Some beds are undulatory near base and may be ripple marked; at the base is a small wedge of quartz which repeats about 4 ft. of section at the road level, but is not present 6 ft. above the road; upper contact is not exposed and lower contact is involved in faulting of obscure nature. | 33.0 |
|  | The sequence from here down to unit 38 is somewhat confused and some sections may be repeated. |  |
| 47 | Sandstone, clay to medium-grained, very light gray (N8), poorly sorted, hard; prominent cleavage; may be weathered portion of underlying unit. | 1.58 |
| 46 | Sandstone, clay to medium-grained, light-orange-gray (5Y5/2), poorly sorted, hard; some of quartz grains are rounded; sand comprises ¼ to ½ of rock; upper contact may be fracture only. | 3.25 |
| 45 | Siltstone, poorly sorted clay to very fine grained sand, light-orange-gray (5Y5/2); upper contact may be bedding plane, fracture, or small fault plane. | 0.75 |
| 44 | Siltstone, coarse-grained, very light gray (N8), hard; few random medium-grained quartz grains; bedding plane upper contact. | 0.58 |
| 43 | Siltstone, coarse-grained, moderate-red-brown (10R4/6); contains about 25 percent fine- to medium-grained quartz grains which are angular to rounded; bedding plane upper contact. | 0.67 |
| 42 | Siltstone, coarse-grained, very light gray (N8); some very fine to medium grained scattered quartz grains; may be a repeat of unit 47; sharp upper contact. | 0.5 |
| 41 | Siltstone, coarse-grained, light-orange-gray (5Y6/1); some very fine to medium-grained quartz grains scattered throughout; gradational upper contact. | 1.67 |
| 40 | Laminite, fine- to medium-grained, finely laminated with laminae ½ to 5 mm thick showing color alteration of light-olive gray (5Y4/2); some of lighter laminae are composed of coarse- to very coarse grained siltstone and some laminae have a single grain thickness of sand grains varying from very fine to medium grained; quartz grains varying from ⅛ to ½ in. in diameter appear to have been dropped onto some of the bedding planes and in some cases have distorted and even disrupted the underlying laminae; bedding surfaces sometimes show well-developed lineations suggestive of current scour marks; some laminae have been distorted; these laminae resemble varves; unit has gradational upper and lower contacts. | 7.5 |
| 39 | Shale, clay, greenish-gray (5GY6/1); upper 2 ft. resembles unit 40 but well-developed cleavage obscures any laminae in the lower 8 ft. (if any are present); quartz pebbles are numerous, are rounded, and attain sizes up to 2½ in. in diameter. It appears that this unit is structureless in the lower part and grades into the overlying lithology; gradational upper contact. | 10.0 |
| 38 | Fault zone; crushed shale. | 0.5 |
| 37 | Shale, greenish-gray (5G6/1); bedding defined by parting; upper contact is fault plane. | 1.0 |
| 36 | Shale, grayish-red (5R4/2); bedding defined by parting; 1- to 4-mm beds; rare pebbles and sand grains; obscure upper contact; base is a fault. | 4.67 |
| 35 | Shale, as unit 37; sharp upper contact. | 2.5 |
| 34 | Shale, as unit 36; gradational upper contact. | 5.0 |
| 33 | Mudstone, coarse-grained, brown-gray (5YR4/1) to medium-dark-gray (N4), hard, homogeneous; no bedding; massive; randomly scattered quartz grains and pebbles up to 3 in. in diameter; pebbles are rounded; gradational upper contact. | 33.0 |
| 32 | Mudstone, as unit 33, with slightly more shale character than unit 33; gradational upper contact. | 2.0 |
| 31 | Polymictic diamictite, medium- to coarse- grained, grayish-red (5R4/2); slight shale texture; abundant quartz grains and pebbles scattered throughout; very poorly sorted throughout; lower part contains more coarse material than upper part and has less shale character; gradational upper contact. | 9.0 |
| 30 | Polymictic diamictite, clay to very coarse grained, mottled grayish-red (5R4/2) to medium-dark-gray (N5); slight greenish appearance; scattered rounded quartz pebbles up to 2 in. in diameter; poorly sorted; sand is over 50 percent of rock; uniform over entire thickness; a 2-ft.- diameter, fine grained, well-sorted, rounded sandstone boulder occurs 51 feet above the base and 7 ft. above the road; lower half varies slightly in color and may have a slightly higher pebble quantity than the upper half; gradational upper contact. | 81.0 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| *Catskill Formation* | | |
| *Duncannon Member* | | |
| (153.38 feet thick; incomplete) | | |
| 29 | Shale, silty, grayish-red (10R4/2); has some pebbles up to ¼ in. in diameter; sharp upper contact. | 2.0 |
| 28 | Siltstone, medium- to coarse-grained, grayish-red (10R4/2) mottled with greenish gray (5GY6/1), massive; has randomly scattered medium- to very coarse grained quartz grains and some pebbles up to 1½ in. in diameter; gradational upper contact. | 5.0 |
| 27 | Sandstone, very fine grained, partly coarse-grained, light-olive-gray (5Y5/2), poorly sorted; rounded quartz pebbles up to 1 in. in diameter; gradational upper contact. | 4.5 |
| 26 | Shale, as unit 29; gradational upper contact. | 2.5 |
| 25 | Siltstone, as unit 28; gradational upper contact. | 2.0 |
| 24 | Sandstone, clay to very coarse grained with average medium-grained, light-olive-gray (5Y5/2), poorly sorted; rounded pebbles up to 3 in. in diameter; massive; quartzitic; gradational upper contact. | 27.0 |
| 23 | Sandstone, medium- to coarse-grained quartz grains in clayey matrix, gray-red (5R4/2); some zones have over 50 percent matrix, some small crossbeds; some zones have pebbles up to ½ in. in diameter; basal 6 in. has numerous quartz pebbles; sharp upper contact. | 4.25 |
| 22 | Sandstone, fine- to medium-grained, grayish-red (5R4/2), quartzitic, massive; gradational upper contact. | 7.5 |
| 21 | Sandstone, very fine grained, grayish-red (5R4/2), quartzitic, bedded; grades into siltstone with scattered medium-grained sand grains in upper 6 in.; sharp upper contact. | 1.5 |
| 20 | Sandstone, medium- to coarse-grained, grayish-red (5R4/2), quartzitic, massive; sharp upper contact. | 8.0 |
| 19 | Sandstone, coarse-grained, grayish-red (5R4/2); clayey matrix; pebbles up to ½ in.; quartzitic; massive; upper 6 in. becomes fine grained; few pebbles up to 1½ in. in diameter; sharp upper contact. | 14.0 |
| 18 | Sandstone, fine-grained, light-olive-gray (5Y6/1), quartzitic, massive; sharp upper contact. | 3.0 |
| 17 | Siltstone, coarse-grained, light-olive-gray (5Y6/1), thin bedded, moderately well indurated; sharp upper contact. | 0.83 |
| 16 | Sandstone, fine- to medium-grained, light-gray (N7), having faint suggestion of greenish-gray (5GY6/1), quartzitic, massive; some parallel beds indicated by color laminae; sharp upper contact. | 17.5 |
| 15 | Shale, light-olive-gray (5Y5/2); prominent cleavage; sharp upper contact. | 0.5 |
| 14 | Siltstone, fine-grained, grayish-red (5R4/2); prominent cleavage; faint trace of bedding; hackly breakup; gradational upper contact. | 11.0 |
| 13 | Siltstone, coarse- to very coarse grained, grayish-red (5R4/2); 1- to 3-in. beds; gradational upper contact. | 7.5 |
| 12 | Sandstone, very fine grained, light-olive-gray (5Y6/1) to greenish-gray (5GY6/1), massive, quartzitic; sharp upper contact. | 1.25 |
| 11 | Sandstone, very fine grained, light-olive-gray (5Y6/1) with some red mottling, blocky to hackly; prominent cleavage; sharp upper contact. | 4.5 |
| 10 | Siltstone, fine-grained, grayish-red (5R4/2); prominent cleavage; gradational upper contact. | 11.0 |
| 9 | Sandstone, very fine grained, grayish-red (5R4/2), massive; parallel bedding laminae; quartzitic; gradational upper contact. | 5.0 |
| 8 | Siltstone, coarse-grained, grayish-red (5R4/2), quartzitic; parallel laminae; gradational upper contact. | 0.25 |
| 7 | Sandstone, as unit 9; gradational upper contact. | 0.21 |
| 6 | Siltstone, as unit 8; gradational upper contact. | 0.17 |
| 5 | Sandstone, as unit 9; gradational upper contact. | 6.0 |
| 4 | Siltstone, as unit 8; gradational upper contact. | 0.42 |
| 3 | Sandstone, fine-grained, grayish-red (5R4/2); small concentrations of medium-grained sand in clayey matrix; prominent cleavage; gradational upper contact. | 2.0 |
| 2 | Siltstone, fine-grained, grayish-red (5R4/2); small concentrations of medium-grained sand in clayey matrix; prominent cleavage; gradational upper contact. | 2.0 |
| 1 | Sandstone, coarse-grained, grayish-red (5R4/2), quartzitic, massive; base behind stone wall. | 2.0 |
| | Base of section. | |
| | Total | 1615.37 |

# SECTION 19

## MAUCH CHUNK FORMATION

Described section of the Mauch Chunk Formation along U.S. Route 209 north of Jim Thorpe. Section is the type locality of the formation. Section starts in transition zone at top of the Pocono and goes upward to near the top of the formation. Base of section is at south end of road exposure on west side of U.S. Route 209. Base of section is approximately at 40°51′54″ N/75°44′11″ W. Section measured by W. D. Sevon.

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| *Mauch Chunk Formation* (1743.06 feet thick; incomplete) | | |
| 198 | Siltstone, fine-grained, grayish-red (5R4/2); grades upward into very fine grained siltstone at top; develops hackly pieces during weathering; upper contact lost in cover. | 12.0 |
| 197 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2), hard, massive; sharp upper contact. | 5.0 |
| 196 | Siltstone, fine-grained, grayish-red (5R4/2); alternating siltstone and very fine grained sandstone in thin beds (⅛ to ¼ in. thick) prominent in lower half of unit; upper half has few hands and some scattered nodules of calcareous material; sharp upper contact. | 6.0 |
| 195 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2); weathers with spheroidal shapes; some thin beds; sharp upper contact. | 12.0 |
| 194 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive; sharp upper contact. | 3.0 |
| 193 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), deeply weathered, pitted; abundant chaotically distributed calcareous material; gradational upper contact. | 1.5 |
| 192 | Siltstone, medium-grained, grayish-red (5R4/2); massive beds; some fine-grained siltstone; parting planes; some 2- to 4-in.-thick beds; some parallel laminae; sharp upper contact. | 7.0 |
| 191 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive; sharp upper contact. | 6.0 |
| 190 | Siltstone, coarse-grained, grayish-red-purple (5RP4/2); massive beds; 6 ft. above base is 2-ft.-thick zone of calcareous nodular material; nodules less than ⅛ in. in diameter with one large mass several in. in diameter; sharp upper contact. | 28.0 |
| 189 | Siltstone, fine- to medium-grained, grayish-red (5R4/2); thin beds ½ to 3 in. thick; more bedded in appearance than beds on either side; sharp upper contact. | 13.0 |
| 188 | Siltstone, coarse- to very coarse grained, grayish-red-purple (5RP4/2); massive beds with some thin 1- to 3-in.-thick interbeds of fine-grained siltstone; 2 ft. 6 in. above base is a zone of chaotically distributed calcareous nodules up to ¼ in. in diameter; zone is laterally variable in thickness from 0 to 9 in.; another zone occurs 14 ft. above base and contains nodules generally less than ⅛ in. in diameter and not as abundant as in lower zone; a third zone occurs below upper contact and is same as middle zone; both middle and upper zones are 2 ft. thick; upper contact is sharp and upper surface has small channel 2 ft. deep and 3 ft. wide. | 20.0 |
| 187 | Siltstone, fine-grained, grayish-red (5R4/2), massive; has shaly appearance; upper 2 ft. 6 in. contains discontinuous bands of calcareous material; bands are ¼ in. thick and up to 1 in. long; many are only up to 1 in. long but always aligned along bedding plane; sharp upper contact. | 7.0 |
| 186 | Sandstone, very fine grained, grayish-red-purple (5RP4/2); breaks into parallel beds; unit is fill in a scour channel which does not show because of limited outcrop; some scattered pits from weathering of calcareous nodular material; sharp upper contact. This unit is the first unit of a high vertical rock face at the south end of a long triangular-shaped stone railroad building. | 6.0 |
| 185 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2), massive; weathers into spheroidal-shaped blocks; 2 ft. 9 in. above the base is a 1-in.-thick deeply recessed zone which may represent a fine-grained siltstone or shale layer; sequence seems to consist of repeating cycles of medium- to coarse-grained siltstone grading upward into finer grained beds; upper bedding planes of finer grained material appear to be mud cracked and have thin curved irregular laminae; sharp upper contact. | 12.0 |
| 184 | Sandstone, very fine grained, grayish-red-purple (5RP4/2); parallel partings; abundant mica flakes; 1 ft. 6 in. above base is 1- to 2-in.-thick zone of calcareous nodules; sharp upper contact. | 1.5 |
| 183 | Siltstone, medium-grained, grayish-red (5R4/2); abundant calcareous nodular material; pitted weathered surface; lower part is chaotic; upper contact is gradational and in places consists of 2 in. of coarse-grained siltstone, then 1 in. of calcareous nodules up to 1 in. thick and 1 in. long aligned along bedding planes. | 0.33–1.0 |
| 182 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2), massive; thickness up to 9 in. (less than indicated because of channeled nature of overlying bed). | 3.0 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 181 | Siltstone, fine- to medium-grained, grayish-red (5R4/2); lower 1 in. contains abundant calcareous nodules up to ¼ in. in diameter; has massive shaly appearance; sharp upper contact. | 6.0 |
| 180 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2), massive; gradational upper contact. | 6.0 |
| 179 | Siltstone, fine-grained, grayish-red (5R4/2); prominent cleavage; recessed; gradational upper contact. | 9.0 |
| 178 | Sandstone, very fine grained, grayish-red-purple (5RP4/2); parallel laminae; abundant coarse-grained mica flakes; massive, sharp upper contact. | 8.0 |
| 177 | Siltstone, fine- to medium-grained, grayish-red (5R4/2); 6-in.-thick zone of calcareous nodules with pitted weathered surface occurs 1 in. above base; sharp upper contact. | 2.0 |
| 176 | Sandstone, as unit 178; crops out at the railroad bed level at north end of low retaining wall; sharp upper contact. | 6.0 |
| 175 | Covered interval, in front of concrete foundation of old building. | 6.0 |
| 174 | Siltstone, coarse- to very coarse grained, grayish-red-purple (5RP4/2), massive; upper contact lost in cover. | 8.0 |
| 173 | Siltstone, medium-grained, grayish-red (5R4/2), massive; 2-in.- to 2-ft.-thick beds separated by 1- to 3-in.-thick fine-grained siltstone beds; mainly covered in upper 6 ft.; sharp upper contact. | 34.0 |
| 172 | Covered interval, 46-ft.-long stone retaining wall; rock dips 40° N; rock on north end of wall appears to be the same as unit 171; about 10 ft. exposed; sharp upper contact. | 30.0 |
| 171 | Siltstone, medium-grained, grayish-red (5R4/2); base is curved scour channel, shows scour patterns; basal 6 in. has small pits where calcareous material has been weathered; some calcareous nodules; ½- to 2-in.-thick beds; some crossbeds; lower 3 ft. appears to be channel fill material; rock abuts against stone wall. | 12.0 |
| 170 | Siltstone, fine-grained, grayish-red (5R4/2), thin-bedded; crossbeds; alternating with medium-grained siltstone in massive beds up to 8 in. thick. | 10.0 |
| 169 | Siltstone, medium-grained, grayish-red (5R4/2), massive; beds 6 in. to 1 ft. thick; sharp upper contact. | 11.0 |
| 168 | Sandstone, very fine grained, grayish-red-purple (5RP4/2); basal 6 in. has pitted holes up to ¼ in. in diameter resulting from weathering of calcareous nodules; massive; gradational upper contact. | 6.0 |
| 167 | Siltstone, medium-grained, grayish-red (5R4/2); massive-appearing beds weather to ⅛- to 1-in.-thick beds; some crossbeds; gradational upper contact. | 20.0 |
| 166 | Channel fill, steep-sided channel 23 ft. deep and 15 to 20 ft. wide at top is cut into rock similar to unit 165; uniformly tapering sides meet at 2- to 3-ft.- wide base. Sequence starting at top:<br>10′ Siltstone, medium- to coarse-grained, grayish-red (5R4/2); some shale partings; thin beds; channel curvature; some beds thin and pinch out laterally; upper 2 ft. has parallel-sided beds.<br>2′ Sandstone, very fine grained, grayish-red-purple (5RP4/2); variable lateral thickness; upper surface is a shale parting.<br>2′ Sandstone, very fine grained, grayish-red-purple (5RP4/2); 3 massive beds, separated by shale partings, vary laterally and pinch out; irregular upper surface is a shale parting.<br>1′3″ Sandstone, very fine grained, grayish-red-purple (5RP4/2); ¼-in.-thick shale at top.<br>8′ Sandstone, very fine grained, grayish-red-purple (5RP4/2); massive crossbeds and parallel-sided beds thin rapidly laterally and pinch out; upper contact marked by ¼- to ½-in.-thick shale. | 23.0 |
| 165 | Sandstone, very fine grained, grayish-red-purple (5RP4/2); parallel laminae; 2-ft.-thick beds with shale partings between massive beds; 10 ft. above base grades into coarse-grained siltstone; top of this unit is in sharp contact with the overlying unit (166) which is a 23-ft.-deep scour channel cut into rock of apparently the same lithology as this unit (165); exposed behind large oil tank. | 20.0 |
| 164 | Shale, grayish-red (5R4/2), deeply recessed; grades up into fine- to medium-grained siltstone; upper 6 in. is conglomerate zone of small shale chips and calcareous nodules up to ¼ in. in diameter; sharp upper contact. | 1.6 |
| 163 | Siltstone, coarse-grained, grayish-red-purple (5RP4/2); basal 6 in. contains grayish-red shale chips up to 1 in. long that appear to have been torn from the underlying unit; parallel laminae; 2- to 4-ft.-thick massive beds alternate with 1- to 6-in.-thick beds of fine-grained siltstone; upper third of unit is medium-grained grayish-red (5R4/2) siltstone with irregularly shaped curved laminae beds; sharp upper contact. | 25.0 |
| 162 | Siltstone, medium-grained, grayish-red (5R4/2); massive beds about 2 ft. thick break up into 2- to 4-in.-thick beds and alternate with 1- to 2-in.-thick beds of fine-grained siltstone; grades up into shale in upper 2 in.; sharp upper contact. | 9.0 |
| 161 | Siltstone, fine- to coarse-grained, grayish-red (5R4/2); ½- to 2-in.-thick beds are generally less than 1 in. thick; few beds up to 4 in. thick; 4 ft. above base is 6-in.-thick zone with abundant shale chips less than ¼ in. in diameter and some calcareous nodules; fine-grained siltstone below shale-chip zone; medium- to coarse-grained siltstone above shale-chip zone; sharp upper contact. | 13.6 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 160 | Siltstone, medium-grained, grayish-red (5R4/2) in lower 2 ft.; grades upward into coarse-grained siltstone; lower 4 ft. is made up of thin beds ¼ to 2 in. thick and is a somewhat recessed zone; grades upward into more massive 1- to 4-in.-thick beds; sharp upper contact. | 20.0 |
| 159 | Sandstone, very fine grained, grayish-red-purple (5RP4/2); abundant coarse-grained mica flakes; massive in appearance; breaks up into 2- to 6-in.-thick beds; some parallel laminae; sharp upper contact. | 9.0 |
| 158 | Siltstone, medium-grained, grayish-red (5R4/2); beds are 2 to 4 in. thick; some break up into thinner beds; sharp upper contact. | 14.0 |
| 157 | Covered interval, debris below stone retaining wall; outcrop appears halfway along length of wall. | 10.0 |
| 156 | Siltstone, coarse-grained, some very fine grained sandstone, grayish-red-purple (5RP4/2); 2½ ft. above base is curved surface, presumably base of channel fill; surface has abundant narrow fan-shaped scour patterns; massive unit; some very fine grained siltstone beds ⅛ to ¼ in. thick normal to bedding in upper part may be squeezed or mud-crack fills; parallel laminae in upper part; upper contact lost in cover. | 10.0 |
| 155 | Siltstone, medium- to coarse-grained, grayish-red-purple (5RP4/2); massive with beds 2 to 7 in. thick; generally recessed zone between more massive units; some thin fine-grained siltstone beds between coarser beds; some parallel laminae; upper contact sharp. | 14.0 |
| 154 | Siltstone, coarse-grained, grayish-red-purple (5RP4/2), massive; some parallel laminae on weathered surface; 5 ft. above base unit begins to display beds 1 to 2 in. thick with some crossbeds; upper 7 ft. is coarse-grained siltstone grading upwards into medium-grained siltstone in upper half of unit; uppermost 2 ft. contains ½- to 1-in.-thick beds; upper contact is gradational but appears sharp because of bedding-plane parting. | 28.0 |

Section from base to this point has been along the west side of U.S. Route 209 and the base of unit 154 is picked along U.S. Route 209. The unit is then projected across the highway and picked up along the Lehigh Valley Railroad below highway level. The section along the railroad starts in unit 154 at the north end of a 60-ft.-long stone retaining wall. Twelve feet of medium-grained siltstone, presumably unit 153, occurs between the north end of the wall and the picked base of unit 154. Units 154–198 occur along railroad.

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 153 | Siltstone, medium-grained, grayish-red (5R4/2), massive; upper 2 ft. composed of thinner beds; sharp upper contact. | 6.0 |
| 152 | Siltstone, fine- to medium-grained, grayish-red (5R4/2); fine-grained siltstone occurs in ¼- to 1-in.-thick beds whereas the medium-grained siltstone occurs in thicker beds; 12 ft. above base is highway sign 5/20; 16 ft. above base is a 9-in.-thick zone with red shale chips in medium- to coarse-grained siltstone matrix; sharp upper contact. | 18.0 |
| 151 | Siltstone, medium-grained, grayish-red (5R4/2), massive; sharp upper contact; has some parallel and some cross laminae in upper 1 ft. | 6.5 |
| 150 | Siltstone, medium-grained, grayish-red (5R4/2), massive; sharp upper contact. | 3.5 |
| 149 | Siltstone, very coarse grained, grayish-red-purple (5RP4/2), quartzitic, massive; sharp upper contact. | 6.0 |
| 148 | Siltstone, medium-grained, grayish-red (5R4/2); beds 1 to 3 in. thick in lower half with beds up to 2 ft. thick in upper half; 47 ft. above base is a cast on the bottom of a bedding surface of an elongate depression which may represent the position of a long piece of wood. A fan-shaped structure with its apex at the center of the depression fans out normal to the depression and may represent a scoured surface created by water flowing under a piece of wood. Fifty-three and one-half ft. above the base are some ripple-marked surfaces, and the uppermost 4 ft. has irregular current laminae which may be ripple drift laminae. Also present is some channel-fill material; sharp upper contact. | 57.0 |
| 147 | Siltstone, coarse-grained, grayish-red (5R4/2), massive, with beds 2 to 6 in. thick; parallel laminae; sharp upper contact. | 18.0 |
| 146 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2); occurs in beds ½ to 6 in thick; thicker beds are coarser; sharp upper contact. | 10.0 |
| 145 | Covered interval, presumably same as unit 144. | 10.0 |
| 144 | Siltstone, medium-grained, grayish-red (5R4/2); beds ¼ to ½ in. thick; upper contact lost in covered interval. | 8.0 |
| 143 | Siltstone, coarse-grained, grayish-red-purple (5RP4/2); abundant mica; basal 2 ft. contains numerous scattered calcareous nodules 1 to 3 mm in diameter; pitted weathered surface; massive; sharp upper contact. | 11.0 |
| 142 | Covered interval, presumably same as unit 143. | 3.0 |
| 141 | Siltstone, coarse- to very coarse grained, grayish-red-purple (5RP4/2), massive; many parallel-sided laminae; quartzitic; sharp upper contact. | 3.0 |
| 140 | Siltstone, coarse- to very coarse grained, grayish-red-purple (5RP4/2); beds 2 to 3 in. thick; recessed zone; sharp upper contact. | 3.0 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 139 | Siltstone, as unit 141. | 15.0 |
| 138 | Siltstone, medium-grained, grayish-red (5R4/2); ⅛- to ¼-in.-thick beds in units 1 to 1½ ft. thick alternating with coarse-grained siltstone in more massive beds ½ to 1½ ft. thick; may change lithology laterally; may be channel filling; sharp upper contact. | 8.0 |
| 137 | Siltstone, coarse-grained, grayish-red-purple (5RP4/2); massive; sharp upper contact. | 8.0 |
| 136 | Covered interval, probably same as unit 137. | 10.0 |
| 135 | Siltstone, medium-grained, grayish-red (5R4/2), massive in lower three-fourths and bedded in upper fourth; upper contact obscured by cover. | 5.5 |
| 134 | Siltstone, medium-grained, grayish-red (5R4/2); calcareous nodules from ¼ to 1 in. in diameter but generally less than ¼ in. in diameter; greatest nodule concentration in lowermost 4 in.; upper 4 in. has very fine grained sand matrix and fewer nodules, some of which are concentrated along planes; numerous red shale chips up to ½ in. long; pitted weathered surface; gradational upper contact. | 0.67 |
| 133 | Siltstone, fine-grained, grayish-red (5R4/2); many beds ⅛ to ½ in. thick; between 4 in. and 10 in. above base are a number of calcareous nodules and lenses, appear to be same as surrounding rock but calcareous when fresh, lenses 1 to 4 in. long and nodules to 2 in. in diameter; sharp upper contact. | 1.75 |
| 132 | Siltstone, fine-grained, grayish-red (5R4/2), composed of many beds ½ to 1 in. thick; some cleavage tendency; sharp upper contact. | 7.0 |
| 131 | Covered interval, presumably same as unit 132. | 6.0 |
| 130 | Sandstone, very fine grained, grayish-red-purple (5RP4/2); basal and uppermost beds are massive; central part contains 1-in.-thick beds; 8 ft. above base is plane with concentration of red shale chips up to 1 in. long aligned parallel with bedding; 11 ft. above base is another plane of shale chips and the interval between planes of chips has scattered shale chips; sharp upper contact. | 16.0 |
| 129 | Siltstone, medium-grained, grayish-red (5R4/2), mostly covered; apparently consists of 1-in.-thick beds interbedded with thicker beds; sharp upper contact. | 14.0 |
| 128 | Siltstone, coarse-grained, grayish-red-purple (5RP4/2); massive, quartzitic; lower 12 ft. is massive while upper 4 ft. has 2- to 4-in.-thick beds; upper contact obscured by cover. | 16.0 |
| 127 | Siltstone, fine-grained, grayish-red (5R4/2); some thin beds of coarse-grained siltstone; beds ½ to 1 in. thick; sharp upper contact. | 1.33 |
| 126 | Siltstone, coarse-grained, grayish-red-purple (5RP4/2), massive, quartzitic; sharp upper contact. | 8.75 |
| 125 | Siltstone, coarse-grained, grayish-red-purple (5RP4/2); ½- to 7-in.-thick beds; some beds wedge shaped; channel-fill material; sharp upper contact. | 5.42 |
| 124 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive, quartzitic; weathering breaks rock into 4-in.- to 1-ft. thick pieces; base is irregular and channeled in underlying unit; sharp upper contact. | 17.0 |
| 123 | Siltstone, fine-grained, grayish-red (5R4/2), apparently thin bedded; prominent cleavage; has shattered appearance; sharp upper contact; irregular contact with overlying channel. | 1.67 |
| 122 | Siltstone, coarse-grained, grayish-red-purple (5RP4/2); many beds ½ to 2 in. thick; some thin very fine grained sandstone beds in lower 3 ft.; becomes fine to medium grained in upper half, and becomes grayish red (5R4/2); sharp upper contact. | 20.0 |
| 121 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive in apparently one bed; sharp upper contact. | 9.0 |
| 120 | Siltstone, coarse-grained, grayish-red-purple (5RP4/2); several 1- to 4-in.-thick beds; forms recessed zone between more massive units; gradational in uppermost 8 in. into fine-grained siltstone which is grayish-red (5R4/2); sharp upper contact. | 4.5 |
| 119 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive; some parallel laminae; sharp upper contact; upper surface is plane along which water is riding as it cuts into weaker overlying unit. | 5.5 |
| 118 | Siltstone, coarse-grained, grayish-red-purple (5RP4/2); many ½- to 2-in.-thick beds; some internal channel fills; some thin shale partings; partings have pimpled bedding surfaces; possible mud cracks; one tubular structure subparallel to bedding is 1 in. in diameter and 7 in. long and has shaly coating around siltstone tube fill; irregular marks on bedding planes may be trails; sharp upper contact. | 12.5 |
| 117 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive; sharp upper contact. | 5.0 |
| 116 | Siltstone, coarse-grained, grayish-red (5R4/2); some fine-grained siltstone; base of unit indicates that it is channel-fill material; considerable lateral grain-size variation; wedges out laterally; sharp upper contact. | 6.0 |
| 115 | Sandstone, as unit 117. | 7.5 |
| 114 | Siltstone, coarse-grained, grayish-red (5R4/2); ½- to 2-in.-thick beds; a channel fill occurs at base and is 7 in. deep and 1 ft. 8 in. wide with long dimension normal to rock face; sharp upper contact; this unit occurs at road sign Jct. PA 903. | 3.0 |
| 113 | Sandstone, very fine to fine-grained, grayish-purple (5RP4/2); basal and upper 4 ft. are massive beds; central part has 1-in.-thick beds; sharp upper contact. | 10.0 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 112 | Siltstone, medium-grained, grayish-red (5R4/2); numerous ¼- to 1-in.-thick beds; some 2-in.-thick beds; 11 in. above base is bedding surface with asymmetrical ripple marks; some beds grade upward into fine-grained siltstone and have pimpled upper bedding surfaces; slickensides are abundant and crosscut bedding; 10 ft. above base is the base of a channel fill which has relief of at least 5 ft.; 17 ft. above the base is the base of a 2-ft.- thick massive bed; upper 10 ft. contains somewhat more massive beds; sharp upper contact. | 37.0 |
| 111 | Siltstone, very coarse grained, grayish-red-purple (5RP4/2), massive, quartzitic; sharp upper contact. | 4.0 |
| 110 | Siltstone, very coarse grained, grayish-red-purple (5RP4/2), massive quartzitic; uppermost 2 in. grades up into grayish-red (5R4/2) shale; sharp upper contact. | 14.0 |
| 109 | Covered interval. | 32.0 |
| 108 | Siltstone, coarse-grained, grayish-red-purple (5RP4/2), massive; beds 2 in. to 1 ft. thick; upper contact obscured by cover. | 14.0 |
| 107 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2), interlaminated with very fine grained sandstone; many ¼- to 2-in.-thick beds; some channeling; partially covered; upper contact obscured but probably sharp. | 24.0 |
| 106 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive, quartzitic; 3- to 9-in.-thick beds; sharp upper contact. | 5.0 |
| 105 | Siltstone, fine- to medium-grained, grayish-red (5R4/2); numerous beds ½ to 1 in. thick; some channeling and lateral variation to very fine grained sandstone; sharp upper contact. | 8.0 |
| 104 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), quartzitic; basal 10 in. contains red shale chips up to 8 in. long but generally 1 to 3 in. long; chips tend to be oriented parallel with bedding and are concentrated along distinct planes; discontinuous zone of shale chips occurs 1 ft. 4 in. above base; massive unit with 4-in.- to 1-ft.-thick beds; total thickness of unit is 3 ft. more than given because of channeling of overlying unit; sharp upper contact. | 10.42 |
| 103 | Siltstone, coarse-grained, grayish-red (5R4/2); thin irregular beds; some interlaminated very fine grained sandstone beds; some channeling filled with very fine grained sandstone up to 8 in. thick; sharp upper contact. | 7.67 |
| 102 | Sandstone, very coarse grained, grayish-red-purple (5RP4/2), quartzitic, massive; laterally thickens to 2½ ft.; sharp upper contact. | 2.0 |
| 101 | Siltstone, coarse-grained, grayish-red (5R4/2); thin irregular beds; some interlaminated very fine grained sandstone beds; sharp upper contact. | 2.0 |
| 100 | Sandstone, very fine grained, grayish-red-purple (5RP4/2); massive with beds 2 to 9 in. thick; sharp upper contact. | 3.83 |
| 99 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive, quartzitic; beds vary from few in. to several ft. in thickness and are separated by thin siltstone layers, 26 ft. above base is base of a 2-ft.-thick zone of ½- to 1-in.-thick irregular beds which grade into overlying massive unit; uppermost bed is massive and 10 ft. thick; sharp upper contact. | 59.0 |
| 98 | Sandstone, very fine grained, grayish-red-purple (5RP4/2); interlaminated with fine-grained, grayish-red (5R4/2) siltstone; many 1- to 10-in.-thick beds; sharp upper contact; upper part of this unit is behind traffic light control box which is on line with the center of the bridge across the Lehigh River. | 17.0 |
| 97 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), quartzitic; 2 massive 2-ft.-thick beds which fine upward into medium-grained siltstone in upper half of bed; sharp upper contact. | 4.0 |
| 96 | Sandstone, very fine grained, grayish-red-purple (5RP4/2); interlaminated with fine-grained, grayish-red (5R4/2) siltstone; many 1- to 10-in.-thick beds; some sandstone beds thin laterally to zero thickness; channeling, crossbedding in some sandstone beds; parallel laminae in some beds; weathers to thin beds and in general contrasts to surrounding beds; sharp upper contact. | 22.0 |
| 95 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive, quartzitic; sharp upper contact. | 12.83 |
| 94 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), quartzitic; unit is a wedge between two siltstone beds; unit thins to nothing in one direction and thickens to 1 ft. 6 in. in other direction; sharp upper contact. | 0.25 |
| 93 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), quartzitic, massive; lower half is one massive bed while upper half is composed of beds 1 to 2 ft. thick separated by ⅛- to 2-in.-thick shale layers; uppermost bed grades upward into fine-grained siltstone; symmetrical ripple marks on upper surface; sharp upper contact. | 38.0 |
| 92 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), quartzitic; several beds 5 in. to 1 ft. thick; uppermost bed grades upward into 6-in.- thick fine-grained siltstone; sharp upper contact. | 3.08 |
| 91 | Sandstone, very fine grained, grayish-red-purple (5RP4/2); thin ¼- to 2-in.-thick beds; may thin laterally to 1 in. thick; contains ⅛-in.-thick interlaminated shales; sharp upper contact. | 0.5 |
| 90 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), quartzitic; single massive bed; sharp upper contact. | 3.0 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 89 | Sandstone, very fine grained, grayish-red-purple (5RP4/2); some medium- to coarse-grained siltstone layers interbedded in ½- to 6-in.-thick sandstone beds; wavy parallel laminae, possibly some channeling; thin-bedded appearance in contrast to adjacent massive beds; sharp upper contact. | 6.0 |
| 88 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), quartzitic, massive; 2-in. to 2-ft.-thick beds; basal 8 in. has color mottling and some small calcareous flakes up to 3 mm in length; 4 ft. above the base is a 1-in.-thick fine-grained siltstone which separates two massive beds; sharp upper contact. | 6.33 |
| 87 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), quartzitic; basal 1 in. is medium-grained siltstone which grades up into sandstone; uppermost 1 in. is also medium-grained siltstone with sharp lower contact and gradational upper contact. | 0.5 |
| 86 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), quartzitic, massive; some wavy laminae; some color mottling; sharp upper contact. | 17.0 |
| 85 | Sandstone, very fine to fine-grained, interlaminated with and in some cases grading up into coarse-grained siltstone, grayish-red (5R4/2) with some light gray (N7) in coarser sandstone; cross laminae in sandstone; sharp upper contact; uppermost bed is siltstone. | 1.42 |
| 84 | Sandstone, fine-grained, light-gray (N7) with slight grayish-red tint, quartzitic, massive; 1 ft. above base is base of a 1-ft.-4-in.- thick zone of thin beds which vary laterally from 1 to 8 in. thick; upper 1 ft. contains several 1- to 2-in.-thick beds; sharp upper contact. | 19.0 |
| 83 | Sandstone, fine-grained, grayish-red-purple (5RP4/2); many massive beds 4 in. to 2 ft. thick; some fine-grained siltstone between massive beds; sharp upper contact. | 10.0 |
| 82 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive; thickens laterally to 1 ft. 6 in.; contacts marked by ⅛- to ¼-in.-thick grayish-red (5R4/2) shale; sharp upper contact. | 0.33 |
| 81 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), quartzitic, massive; shale partings up to ⅛ in. thick between massive beds; some parallel-sided laminae; some cross laminae; suggestion of some channeling; sharp upper contact. | 5.0 |
| 80 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), with interbedded grayish-red (5R4/2) shale; unit is a channel fill; sequence from top:<br>5 in., sandstone, with several 1-mm-thick shale partings in upper and lower 1 in.<br>5 in., siltstone grading upward into shale.<br>2 in., sandstone.<br>Laterally the sequence thins to zero thickness; sharp upper contact. | 1.0 |
| 79 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), quartzitic, massive; some beds to 4 ft. thick; ⅛-in.-thick shale partings between massive beds; some parallel laminae; some cross laminae; some suggestion of channeling; sharp upper contact. | 12.0 |
| 78 | Siltstone, coarse- to very coarse grained, grayish-red (5R4/2), massive; some contorted bedding laminations; color mottling; sharp upper contact. | 4.67 |
| 77 | Shale, grayish-red (5R4/2); sharp upper contact. | 1.17 |
| 76 | Sandstone, very fine to fine-grained, grayish-red (5R4/2), massive; softer than adjacent beds; gradational upper contact. | 6.0 |
| 75 | Shale, grayish-red (5R4/2); sharp upper contact. | 0.33 |
| 74 | Sandstone, fine-grained, grayish-red-purple (5RP4/2), massive; basal 7 in. is coarse-grained siltstone which grades up into sandstone and contains numerous ⅛- to ¼-in.-diameter calcareous nodules; color mottling; sharp upper contact. | 18.75 |
| 73 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2), massive; 4 ft. above the base is the base of a 1-ft.-4-in.-thick zone containing pitted holes resulting from weathering of calcareous nodules and several discontinuous bands of calcareous material ⅛ to ¼ in. thick; base of this zone marked by a nearly continuous 1-in.-thick calcareous band; gradational upper contact. | 10.0 |
| 72 | Siltstone, fine-grained, grayish-red (5R4/2); gradational upper contact. | 2.0 |
| 71 | Sandstone, very fine grained, grayish-red (5R4/2); basal 2 ft. is coarse-grained siltstone; grades upward into sandstone; massive beds 6 in. to 2 ft. thick; some thin shale partings between massive beds; sharp upper contact. | 18.0 |
| 70 | Siltstone, medium-grained, grayish-red (5R4/2); several fining-upward beds going up into very fine grained siltstone; some calcareous nodules 2 ft. below top and in uppermost 6 in.; sharp upper contact. | 8.0 |
| 69 | Sandstone, medium-grained, grayish-red-purple (5RP4/2), quartzitic, massive; basal 3 in. has pebbles presumably derived from underlying conglomerate; sharp upper contact. | 14.0 |
| 68 | Conglomerate, calcareous nodules up to 2 in. thick and 7 in. long with most material less than 2 in. long; most nodules tend to be plate shaped; calcareous sandstone and red shale; no bedding; chaotic appearance; fine-grained matrix; sharp upper contact. | 3.0 |
| 67 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive; irregular and sharp upper contact. | 2.0 |
| 66 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2), massive; sharp upper contact. | 1.0 |
| 65 | Siltstone, medium- to coarse-grained, grayish-red (5R4/2); ¼- to ½-in. beds; sharp upper contact. | 1.5 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 64 | Siltstone, coarse- to very coarse grained, grayish-red (5R4/2), massive; sharp upper contact. | 7.5 |
| 63 | Siltstone, fine-grained, grayish-red (5R4/2); sharp upper contact. | 2.0 |
| 62 | Sandstone, very fine grained, grayish-red (5R4/2), massive; sharp upper contact. | 2.5 |
| 61 | Siltstone, comprises several fining-upward sequences starting with very fine grained sandstone and grading up into thin shale layer at top; sequences range from 1 in. to 1 ft. thick; 2½ ft. above base is a bedding-plane surface with asymmetrical ripple marks and possibly mud cracks; cross laminae also noted; sharp upper contact. | 8.0 |
| 60 | Sandstone, very fine to fine-grained, grayish-red-purple (5RP4/2); basal 8 in. is a conglomerate of calcareous nodules, underlying siltstone has flame-type structure projecting up into conglomerate; sharp upper boundary for the conglomerate; 9 in. above conglomerate contains scattered calcareous nodules and pitted weathered surface; sharp upper contact. | 3.25 |
| 59 | Siltstone, fine- to medium-grained, grayish-red (5R4/2); some discontinuous calcareous zones ⅛ to ¼ in. thick; sharp upper contact. | 0.5 |
| 58 | Siltstone, very coarse grained, grayish-red (5R4/2); contains some scattered calcareous nodules ⅛ to ¼ in. in diameter in lower 6 in.; concentration of calcareous cement 1 in. thick occurs 2 in. below top; sharp upper contact. | 1.25 |
| 57 | Siltstone, coarse-grained, grayish-red (5R4/2); 4 in. above base is a nearly continuous calcareous zone 2 in. thick which weathers to pale red (10R6/2) and very light gray (N8), varies laterally in position above base; a discontinuous 1-in.- thick calcareous zone occurs 1 to 2 in. below the 2-in.-thick zone; laterally the unit thickens and another nearly continuous calcareous zone 2 to 3 in. thick appears below the other two zones; sharp upper contact. | 1.0 |
| 56 | Siltstone, medium-grained, grayish-red (5R4/2); irregular bedding laminae; zones with numerous light-colored calcareous nodules; sharp upper contact; nodule zones as follows from top:<br>8 ft. 10 in. to 9 ft. 2 in. No nodules.<br>8 ft. to 8 ft. 10 in. Nodule zone.<br>3 ft. 6 in. to 8 ft. No nodules.<br>2 ft. 8 in. to 3 ft. 6 in. Nodule zone.<br>2 ft. to 2 ft. 8 in. No nodules.<br>0 ft. to 2 ft. Nodule zone. | 9.17 |
| 55 | Siltstone, very coarse grained, grayish-red (5R4/2), massive; sharp upper contact. | 0.58 |
| 54 | Siltstone, very coarse grained, grayish-red (5R4/2); becomes medium grained in upper part; 6-in. to 1-ft.-thick discontinuous zones of calcareous nodules have their bases at 8 ft., 10 ft., and 12 ft. above the base of the unit; sharp upper contact. | 14.67 |
| 53 | Siltstone, coarse-grained, grayish-red (5R4/2); basal 6 in. has ½- to 1-mm-thick bedding laminae and some 1- to 5-mm-thick interlaminated very fine grained sandstone beds; upper 1 ft. 6 in. contains scattered calcareous nodules up to 3 in. in diameter; sharp upper contact. | 4.25 |
| 52 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), quartzitic; 1- to 2-in.-thick pitted weathered surface resulting from weathering of calcareous nodules at base; sharp upper contact. | 2.5 |
| 51 | Siltstone, medium-grained, grayish-red (5R4/2); gradational upper contact. | 0.58 |
| 50 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), quartzitic, massive; 1-in.-thick pitted surface resulting from weathering of calcareous nodules occurs 1½ in. above base; sharp upper contact. | 0.5 |
| 49 | Siltstone, medium-grained, grayish-red (5R4/2); contains several sandstone beds as follows: 4 in. above base is 2½-in.-thick very fine grained sandstone, grayish-red-purple; 1 ft. 6 in. above base is 2½-in.-thick very fine grained sandstone, grayish-red-purple; 1 ft. 8½ in. above base is 4-in.-thick zone of 1- to 2-mm siltstone beds interlaminated with very fine grained sandstone beds 2 to 4 mm thick; sharp upper contact. | 2.25 |
| 48 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), quartzitic, massive; sharp upper contact. | 3.0 |
| 47 | Siltstone, medium-grained, grayish-red (5R4/2); thin parallel laminae; sharp upper contact. | 10.67 |
| 46 | Siltstone, very coarse grained, grayish-red (5R4/2), massive; basal 9 in. has disseminated calcareous material in small concentrations; weathered surface has pitted appearance; gradational upper contact. | 4.0 |
| 45 | Siltstone, coarse-grained, grayish-red (5R4/2), massive; upper 2 ft. may be animal burrowed; some flake-shaped calcareous nodules in lower 1 ft. of uppermost 2-ft. zone; sharp upper contact. | 8.5 |
| 44 | Sandstone, fine-grained, grayish-red-purple (5RP4/2), massive, uniform; sharp upper contact. | 2.83 |
| 43 | Sandstone, very fine grained, grayish-red-purple (5RP4/2); massive but contains several coarsening-upward sequences starting with coarse-grained siltstone and grading upward into very fine grained sandstone within ½ in.; sharp upper contact. | 1.25 |
| 42 | Siltstone, fine-grained, grayish-red (5R4/2); thin parallel-sided beds; sharp upper contact. | 1.08 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 41 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive, uniform; 2-ft.-thick zone of calcareous nodular material starts 1 ft. 8 in. above base; sharp upper contact. | 5.75 |
| 40 | Siltstone, fine-grained, grayish-red (5R4/2); sharp upper contact. | 0.08 |
| 39 | Sandstone, very fine grained, grayish-red-purple (5RP4/2); a 4-in.-thick zone of calcareous nodular material starts 2 in. above base; zone contains flake-shaped nodules and disseminated calcareous material; sharp upper contact. | 1.75 |
| 38 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive, hard; sharp upper contact. | 0.17 |
| 37 | Siltstone, fine-grained, grayish-red (5R4/2), sharply gradational into overlying unit. | 0.17 |
| 36 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), sharply gradational into overlying unit. | 0.33 |
| 35 | Shale, grayish-red (5R4/2); sharp upper contact. | 0.02 |
| 34 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive, hard; sharp upper contact. | 1.25 |
| 33 | Shale, grayish-red (5R4/2); sharp upper contact. | 0.08 |
| 32 | Sandstone, medium-grained, grayish-red-purple (5RP4/2); calcareous material disseminated throughout etches upon weathering to reveal cross laminae; sharp upper contact. | 3.0 |
| 31 | Conglomerate, 25 to 35 percent ⅛- to ½-in.-diameter rounded to subangular quartz grains set in coarse to very coarse grained sandstone matrix, grayish-red-purple (5RP4/2); rare pebbles up to 2 in. in diameter; deeply pitted weathered surface; calcareous cement; gradational upper contact. | 3.5 |
| 30 | Sandstone, fine- to medium-grained, grayish-red-purple (5RP4/2), color-mottled with light gray; parallel-sided laminae; becomes medium- to coarse-grained in upper half; basically massive with no breaks or partings but considerable variation in weathered surface appearance as result of internal lithological variations; sharp upper contact; variations from top are:<br>(distance is from base of unit)<br>9 ft. 9 in. Zone 1 ft. 6 in. thick contains ⅛- to ¼-in. quartz pebbles with occasional pebbles to 1 in. in diameter and calcareous nodules to 7 in. in diameter; sharp upper contact.<br>9 ft. 9-in.-thick zone of sandstone containing no pebbles in lower part but increasing numbers of pebbles upward.<br>8 ft. 1-ft.-thick zone with 25 to 35 percent rounded to subangular quartz pebbles.<br>7 ft. Zone of randomly scattered rounded quartz pebbles ¼ to 1 in. in diameter.<br>4 ft. 2½-ft.-thick zone which varies laterally to 4 ft. contains white calcareous nodules up to 5 in. in diameter which weather giving rock pitted appearance; also contains disseminated calcareous concentrations which do not have nodular character; larger nodules have sinuous planes of red shaly material crisscrossing the nodules.<br>10 in. Siltstone, fine-grained; discontinuous zone up to 1 in. thick. | 11.25 |
| 29 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive, quartzitic; grades upward into fine-grained sandstone; upper 4 in. is medium-grained siltstone, grayish-red (5R4/2), which has a gradational lower contact with sandstone and is crosscut normal to bedding by a sinuous ¼-in.-thick sandstone dike; sharp upper contact. | 2.0 |
| 28 | Sandstone, fine-grained, light-gray (N7) to medium-light-gray (N6), quartzitic, massive; 2- to 6-in.-thick parallel-sided beds; basal contact marked only by color change; upper contact sharp and channeled with relief up to 1½ ft. | 14.0 |
| 27 | Sandstone, fine-grained, grayish-red-purple (5RP4/2), massive; parallel-sided beds 2 to 6 in. thick; occasional red shale chips up to 1 in. in diameter; some lenses of shale may be present; base shows some mixing of sandstone with underlying siltstone; nearly quartzitic; 1- to 3-mm-thick parallel laminae in upper 1 ft.; sharp upper contact. | 14.75 |
| 26 | Siltstone, fine-grained, grayish-red (5R4/2); basal 1 in. is shale which grades upward into siltstone; massive; breaks up into platy pieces; sharp upper contact is irregular as result of loading from overlying sandstone. | 2.0 |
| 25 | Sandstone, fine-grained, grayish-red (5R4/2), punky as result of weathering of calcareous material; cross laminae, particularly above 4 ft. above the base; sharp upper contact. | 7.0 |
| 24 | Siltstone, fine-grained, grayish-red (5R4/2); 2 in. above base grades up into 3-in.-thick very fine grained sandstone; gradational upper contact | 2.0 |
| 23 | Sandstone, medium-grained in basal 5 in., remainder is fine grained, grayish-red (5R4/2); sharp upper contact. | 1.25 |
| 22 | Siltstone, fine-grained, grayish-red (5R4/2); sharp upper contact. | 0.02 |
| 21 | Sandstone, medium-grained, light-gray (N7); some internal bands of grayish red (5R4/2); massive; hard; sharp upper contact. | 0.92 |

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 20 | Shale, dark-reddish-brown (10R3/4); breaks up into paper-thin pieces; sharp upper contact. | 0.01 |
| 19 | Sandstone, medium-grained in lower half, grades into fine-grained in upper half, light-gray (N7); sharp upper contact. | 0.08 |
| 18 | Shale, dark-reddish-brown (10R3/4); breaks up into paper-thin pieces; sharp upper contact. | 0.04 |
| 17 | Sandstone, very fine to fine-grained, grayish-red (5R4/2); internal parallel-sided laminae indicated by lighter colored bands; laminae 1 mm thick; sharp and irregular upper contact. | 0.37 |
| 16 | Sandstone, medium- to coarse-grained, light-gray (N7) with thin bands of grayish-red-purple (5RP4/2); cross laminae and parallel laminae; massive; sharp upper contact. | 2.83 |
| 15 | Sandstone, medium-grained, grayish-red-purple (5RP4/2), massive; sharp upper contact. | 0.58 |
| 14 | Shale, dark-reddish-brown (10R3/4); breaks up into paper-thin pieces; sharp upper contact. | 0.33 |
| 13 | Sandstone, medium-grained, grayish-red-purple (5RP4/2), massive; base is covered; sharp and irregular upper contact shows some mixing with overlying unit. | 0.75 |
| 12 | Covered interval, presumably same as unit 11. | 8.0 |
| 11 | Siltstone, coarse- to very coarse grained, grayish-red (5R4/2); weathers to brighter red; massive; disintegrates into hackly pieces; upper contact in covered interval. | 6.5 |
| 10 | Sandstone, very fine grained, grayish-red-purple (5RP4/2), massive; gradational upper contact. | 2.0 |
| 9 | Siltstone, coarse- to very coarse grained, grayish-red (5R4/2); breaks up into thin platy pieces ¼ in. thick; less resistant to weathering than adjacent rocks; gradational upper contact. | 0.58 |
| 8 | Sandstone, very fine to fine-grained, grayish-red-purple (5RP4/2), moderately well indurated, massive; develops spheroidal surfaces during weathering; unit becomes dominantly very fine grained in upper half; gradational upper contact. | 10.0 |
| 7 | Siltstone, grayish-red (5R4/2); base is coarse grained; between 4 to 7 ft. above base unit grades to fine grained; becomes fine to medium grained in upper third; partially covered; upper contact covered but probably sharp. | 44.0 |
| 6 | Siltstone, medium-grained, dusky-yellow (5Y6/4); beds ¼ to 1 in. thick; about 14 ft. above base begins gradational color change to grayish-red (5R4/2); unit becomes more platy in upper part; fine grained in upper 2 ft.; sharp upper contact. | 22.0 |
| 5 | Sandstone, fine-grained, dusky-yellow (5Y6/4), uniform; 5 to 10 percent muscovite and other dark grains; 1- to 2-in.-thick beds; gradational upper contact. | 7.0 |
| 4 | Sandstone, medium- to coarse-grained, olive-gray (5Y5/2); about 5 percent muscovite flakes up to coarse-grained sand size; at 20 ft. above base is 3-ft.-thick zone with coarse- to very coarse grained sand grains; unit predominantly medium grained; 26 ft. above base is 2-ft.-thick zone with a few pebbles up to ¼ in. in diameter; this zone is cross laminated and has pebbles along laminae but majority of pebbles are randomly scattered; sharp upper contact. | 36.0 |
| 3 | Siltstone, medium-grained, grayish-red (5R4/2); weathers to hackly pieces; massive; uniform; partially covered; sharp upper contact. | 30.0 |
| 2 | Sandstone, very fine grained, grayish-red-purple (5RP2/2) color bands; gradational upper contact. | 3.0 |
| 1 | Sandstone, medium- to coarse-grained, light-olive-gray (5Y5/2); about 5 percent muscovite flakes up to coarse-grained sand size; hard; cross laminae; becomes predominantly medium grained in upper part; upper contact is covered but probably gradational. | 10.0 |
|  | Total | 1743.06 |

## SECTION 20

## MAUCH CHUNK-POTTSVILLE FORMATIONS TRANSITION

Described section of part of the Mauch Chunk-Pottsville Formations transition zone. Section is exposed along the south side of U.S. Route 209 north of Jim Thorpe. Base of the section is at road survey marker 4/80, occurs by a roadside spring, and is at the west end of the outcrop. Base of section is approximately at 40°52′21″ N/75°44′45″ W. Section measured by W. D. Sevon.

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| *Mauch Chunk-Pottsville Formations transition zone* (109.92 ft. thick; incomplete) | | |
| 6 | Siltstone, coarse-grained, grayish-red (5R4/2); 5 ft. above base are scattered white calcareous nodular masses; another zone 2 ft. thick occurs 10 ft. above the base and has a very pitted weathered surface; uppermost 10 ft. is structureless and breaks down into hackly pieces; upper contact lost into covered interval. | 30.0 |
| 5 | Sandstone, medium-grained in lower 18 ft. grading upward into fine-grained, micaceous, medium-dark-gray (N4), hard, massive; some parallel laminae; zone 8 to 10 ft. above base contains crossbedding with truncated topsets and tangential bottomsets; another similar zone occurs 12 to 13 ft. above the base; some disturbed bedding (possibly load casting); gradational upper contact; lower contact is an interbedded zone 4 ft. thick. | 24.0 |
| 4 | Sandstone, medium- to coarse-grained, olive-gray (5Y4/2); contains feldspar and mica; grains apparently angular to subangular; basal contact eroded into underlying unit; locally the basal part is conglomeratic with rounded quartz pebbles up to ½ in. in diameter; basically a massive unit; 3½ ft. above base is a laterally nonpersistent zone containing abundant pebbles up to ½ in. in diameter; laterally to the east the unit becomes basically a conglomerate with rounded to subangular quartz pebbles up to 1 in. in diameter; some siltstone chips up to 3 to 4 in. in diameter also occur; bedding is indistinct to absent and the unit is basically massive; between the spring and Jim Thorpe Borough line with survey marker 162–5 (2)/01 + 38 is a long section parallel to strike with very indistinct bedding; some pebbles are up to 2 in. in diameter; some well-defined planes of pebbles; many conglomerate beds are probably lenticular. | 20.0–50.0 |
| 3 | Siltstone, fine- to coarse-grained, light-olive-gray (5Y5/2–5Y4/2); contains very small crossbeds; lower contact is gradational; upper contact is sharp; lower 5 in. of unit is coarse-grained siltstone which grades upward into fine-grained siltstone. | 2.42 |
| 2 | Siltstone, medium-grained, grayish-red (5R4/2); coarse-grained in basal 2 to 3 in.; contains several 1-in.-thick beds of small crossbeds of coarse-grained siltstone which have sharp bases and are gradational upwards into fine-grained siltstone; fine-grained siltstone sometimes has parallel laminations; gradational upper contact. | 2.0 |
| 1 | Sandstone, fine-grained, light-brownish-gray (5YR5/1), massive, structureless, micaceous; sharp upper contact. Base of section. | 1.5 |
| | Total | 109.92 |

## SECTION 21

## ILLINOIAN(?) DRIFT

Section of glacial drift exposed on north side of Pa. Route 443 approximately 1.4 miles west of the junction of Pa. Route 443 and U.S. Route 209 in Lehighton (40°49′03″ N/75°43′43″ W). Section occurs in a small roadside borrow pit and was described on October 28, 1966. Section measured by W. D. Sevon.

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| *Illinoian(?) drift* (14 ft. 3 in. thick; incomplete) | | |
| 4 | Gravel, moderate-reddish-brown (10R4/6), mainly chips of Mahantango shale; some deeply weathered sandstone pebbles up to 6 in. in diameter; some boulders of sandstone and conglomerate up to 2 ft. in diameter; no bedding; probably mixed periglacial rubble and outwash gravel. | 8.0 |
| 3 | Clay, light-gray (N7) to moderate-light-gray (N6), compact, sticky when wet; powdery, white, and silty when dry; sharp upper contact. | 1.5 |
| 2 | Clay, moderate-red (5R4/6) mottled with white, some sand and silt; some rounded, deeply weathered pebbles up to 3 in. in diameter; gradational upper contact. | 1.5 |
| 1 | Till (?), moderate-yellow (5Y7/6) to dark-yellowish-orange (10YR6/6) to light-brown (5YR5/6), heterogeneous mixture of clay, silt, sand, and pebbles; pebbles mainly Mahantango shale up to 2 in. in diameter; some sandstone and siltstone pebbles up to 4 in. in diameter; dominantly clay; abrupt color transition into overlying unit; base covered. | 3.25 |
| | Total | 14.25 |

## SECTION 22

## ALLUVIUM

Description of alluvium exposed along the Lehigh River, ½ mile upstream from the mouth of Aquashicola Creek (40°47′48″ N/75°37′12″ W). Section measured by W. D. Sevon.

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| *Alluvium* (16.33 ft. thick; incomplete) | | |
| 3 | Sand, fine- to medium-grained, clayey, reddish-brown (near moderate-brown (5YR4/4)), slightly coherent; few scattered pebbles up to 1 in. in diameter; upper 6 in. mixed with coal dust. | 6.0 |
| 2 | Gravel, pebbles 2 to 8 mm in diameter mixed with fine- to medium-grained sand; sharp upper contact. | 0.33 |
| 1 | Gravel, boulders up to 4 × 1½ × 1 ft., few exceed 1½ ft. in diameter, most are cobbles and boulders 6 to 12 in. in diameter, fine- to coarse-grained sand matrix; cobbles and boulders are well rounded, tend to have flattened shapes, and are imbricated with upstream dips and long axes oriented both parallel and normal to direction of stream flow; cobbles and boulders are siltstones, sandstones, and conglomerates of Trimmers Rock, Catskill, and Pocono Formations; sharp upper contact; unit extends below water level. | 10.0+ |
| | Total | 16.33 |

## SECTION 23

## ALLUVIUM

Measured section of alluvium along Lehigh River just east of the village of Lehigh Gap (sample locality 3, Plate 2). Petrographic details are given in Tables 9, 10, and 12 and Figures 132 and 133. Section measured by J. B. Epstein.

| *Unit* | *Lithologic description* | *Thickness (in feet)* |
|---|---|---|
| 3 | Sand, very fine to medium-grained, brownish-black (5YR2/1) to black (N1), with abundant coal dust. Lower contact abrupt. | 6.0 |
| 2 | Sand, very fine to medium-grained, with rare rounded pebbles, moderate-yellowish-brown (10YR5/3) and black (N1), containing intermixed coal dust. Lower contact abrupt. | 0.2–0.5 |
| 1 | Sand, fine, muddy, rare scattered pebbles and cobbles, moderate-brown (5YR4/4); base below water. | 2.5+ |
| | Incomplete thickness of alluvium | 8.7–9.0+ |

## SECTION 24

## PHILLIPS PETROLEUM NO. 1 GRAVER ESTATE WELL

Measured section in the Phillips Petroleum Company exploration well No. 1 Graver Estate. Site is located in Towamensing Township, Carbon County (6,950 feet south of latitude 40°52′30″ and 11,320 feet west of longitude 75°35′). Drilling commenced on July 7, 1964, at an altitude of 564 feet and was completed on August 22, 1964, at a total depth of 5,396 feet. Description is from the Geo-Log of the well; identifications are modified from the log. Compiled by J. B. Epstein.

| *Unit* | *Lithologic description* | *Depth (in feet)* |
|---|---|---|
| *Mahantango Formation* | | |
| 43 | Shale, dark-gray, slightly silty, pyritic and micaceous. | 0–90 |
| 42 | Shale, grayish-black to black, slightly silty and pyritic with streaks of dark-gray, very fine grained sandstone with subangular and poorly sorted grains, silty and argillaceous, very slightly dolomitic, hard, tight, traces of fractures with white coarse calcite rhombs; grades into dark-gray, argillaceous, slightly sandy and dolomitic siltstone. | 90–145 |
| 41 | Shale, as unit 43; slightly sandy zone with traces of fossil fragments at 210–215 ft. | 145–280 |
| 40 | No samples. | 280–300 |
| 39 | Shale, dark-gray, slightly silty, pyritic and micaceous, few scattered slightly sandy zones. | 300–380 |
| *Centerfield fossil zone(?)* | | |
| 38 | Shale, dark-gray, slightly silty, pyritic and micaceous, slightly calcareous with few calcite crystals at 381–400 ft., unidentifiable macrofossil material at 390–500 ft., Bryozoa, crinoid columnals, and corals at 500–520 ft. Fault, shallow, hanging wall moving up. | 380–540 |
| *Marcellus Formation* | | |
| 37 | Shale, black, very slightly silty, slightly pyritic, abundant fractures filled with white and clear quartz, slickensides, traces of quartz crystals. | 540–570 |
| 36 | Shale, black, very slightly silty, slightly pyritic and micaceous, indurated. | 570–640 |
| 35 | No samples. | 640–650 |
| 34 | Shale, black, slightly silty, calcareous and pyritic traces of unidentifiable macrofossils, crinoid columnals. | 650–710 |
| 33 | Shale, grayish-black to black, very slightly silty, scattered fractures, some with white, coarse calcite rhombs and quartz crystals, slightly pyritic and micaceous. | 710–1530 |
| 32 | Shale, black, very slightly to slightly calcareous, pyritic. | 1530–1623 |
| *Marcellus Formation, Stony Hollow and Union Springs Members undifferentiated(?)* | | |
| 31 | Limestone, white to light-gray, crypto- to microcrystalline, slightly pyritic. | 1623–1628 |
| 30 | Shale, as unit 32. | 1628–1687 |
| 29 | Limestone, moderate-brown, lithographic (Hazard paint ore?). | 1687–1692 |
| *Marcellus Formation* | | |
| 28 | Shale, grayish-black to black, slightly calcareous, very slightly silty and pyritic, trace of fractures. Fault, shallow, hanging wall moving down. | 1692–1790 |
| 27 | Shale, black, slightly pyritic and micaceous, scattered to moderately abundant fractures with white coarse calcite rhombs and quartz crystals; increased fractures and slickensides at 1850 ft. | 1790–1890 |
| 26 | Shale, grayish-black to black, very slightly silty, slightly calcareous, micaceous and pyritic, scattered fractures; becomes black below 2010 ft.; fault at 2340 ft., steep with hanging wall moving down, increase in fractures and white coarse calcite rhombs; increasingly pyritic at 2680 ft.; increasingly calcareous at 2830 ft. | 1890–3268 |
| *Marcellus Formation, Stony Hollow and Union Springs Members undifferentiated* | | |
| 25 | Limestone, black, crypto- to microcrystalline, very argillaceous, slightly silty and siliceous; interbedded with shale, black, slightly calcareous, pyritic. | 3268–3330 |
| 24 | Limestone, dark-gray to grayish-black microcrystalline, slightly argillaceous and siliceous, very slightly silty; interbedded with shale, black, slightly calcareous, pyritic, increasingly shaly at 3395 ft., trace of fossil fragments at 3448 ft. | 3330–3490 |
| *Buttermilk Falls Limestone and Stony Hollow and Union Springs Members of the Marcellus Formation, undifferentiated* | | |
| 23 | Limestone, dark-gray to grayish-black, crypto- to microcrystalline, argillaceous, slightly silty, scattered fractures with white coarse calcite rhombs and quartz crystals; interbedded and streaked with shale, black, slightly calcareous, pyritic; trace of black chert at 3490 ft.; trace of Tioga(?) bentonite at 3810 ft., mottled medium to light gray, hard, indurated. | 3490–3845 |
| 22 | Shale, black, slightly calcareous and pyritic; interbedded and streaked with limestone, black, microcrystalline, argillaceous, slightly silty. | 3845–4312 |
| 21 | Limestone, medium-light-gray to light-gray, crypto- to microcrystalline, slightly silty; shale, medium-dark-gray. | 4312–4335 |
| 20 | Shale, as unit 22. | 4335–4438 |
| 19 | Limestone, medium-gray to medium-light-gray, crypto- to microcrystalline, slightly silty and siliceous; interbedded with shale, dark-gray to black, slightly calcareous. | 4438–4520 |

| *Unit* | *Lithologic description* | *Depth (in feet)* |
|---|---|---|
| *Esopus and Schoharie Formations, undifferentiated* | | |
| 18 | Shale, grayish-black to black, slightly calcareous, very slightly silty, fissile. | 4520–4620 |
| *Oriskany Group* | | |
| 17 | Sandstone, poor to no sample. | 4620–4655 |
| 16 | Conglomerate, mottled medium-light-gray to dark-gray, fine- to very coarse grained, granules, pebbles, subangular to subrounded to rounded, poorly sorted, siliceous, slightly calcareous; trace of hematite, black shale and pyritic, dark-gray to black, translucent to opaque chert. | 4655–4685 |
| *New Scotland Formation(?)* | | |
| 15 | Shale, black, silty, siliceous; siltstone, black, siliceous; chert, black, silty, argillaceous, slightly calcareous. | 4685–4760 |
| 14 | Shale, grayish-black to black, very slightly silty; streaked with siltstone, black, siliceous; trace of black chert. | 4760–4813 |
| *Coeymans Formation* | | |
| 13 | Limestone, dark-gray to grayish-black, microcrystalline, slightly silty, siliceous and argillaceous, fossiliferous; trace of chert, dark-brown, translucent, fossiliferous; interbedded shale, black, pyritic, fissile, brachiopods, crinoid columnals; scattered fractures with white, coarse, calcite rhombs; becomes increasingly silty below 4900 feet. | 4813–4960 |
| *Decker Formation* | | |
| 12 | Sandstone, mottled light-gray to medium-gray to dark-gray, very fine to coarse-grained, scattered granules and pebbles, subangular to subrounded grains, poorly sorted, calcareous, siliceous, hard, scattered fossils, brachiopods and crinoid columnals, grading to limestone, mottled medium-gray to medium-dark-gray, crypto- to microcrystalline, slightly sandy, fossiliferous, below 4980 ft. has traces of pseudo-oolites and pellets. | 4960–5040 |
| 11 | Sandstone, medium-gray to medium-dark-gray, very fine to fine-grained, subangular, poor to fair sorting; silty, slightly argillaceous and calcareous, quartzitic, hard; grading to siltstone, medium-dark-gray, argillaceous, slightly sandy and calcareous, quartzitic; unidentifiable microfossil material. | 5040–5090 |
| 10 | Conglomerate, white to light-gray, fine- to very coarse grained, granules, pebbles, subangular to subrounded to rounded, poor to fair sorting, slightly calcareous, slightly friable to siliceous, traces of intergranular porosity, secondary quartz crystals and fossils; streaked becoming quartzitic. | 5090–5160 |
| 9 | No samples. | 5160–5170 |
| *Bossardville Limestone* | | |
| 8 | Limestone, dark-brown to gray, lithographic to microcrystalline, slightly argillaceous and silty, traces of pseudo-oolites and fossils. | 5170–5175 |
| 7 | No samples. | 5175–5190 |
| 6 | Shale, black, slightly silty and calcareous, interbedded and streaked with limestone, dark-brown to grayish-black, crypto- to microcrystalline, argillaceous, silty, slightly siliceous, traces of fractures with white, coarse calcite rhombs. | 5190–5195 |
| 5 | No samples. | 5195–5200 |
| 4 | Shale, as unit 6. | 5200–5255 |
| | Fault, steep, hanging wall moving down. | |
| *Poxono Island Formation* | | |
| 3 | Shale, light-greenish-gray to pale-green, waxy, sericitic to mylonitic, front medium and brecciated with stringers of calcite and dolomite, traces of anhydrite; streaked and interbedded limestone, very light gray to pale-green, lithographic, slightly argillaceous, very slightly silty, slightly dolomitic; grading to dolomite, pale-green, micro- to very finely crystalline, slightly silty and argillaceous, fractures and brecciated. | 5255–5345 |
| 2 | No samples. | 5345–5390 |
| 1 | Shale, pale-green, as unit 3; streaked with dolomite, light-gray, crypto- to microcrystalline, slightly calcareous, very slightly silty, trace of anhydrite and pyrite. | 5390–5396 |

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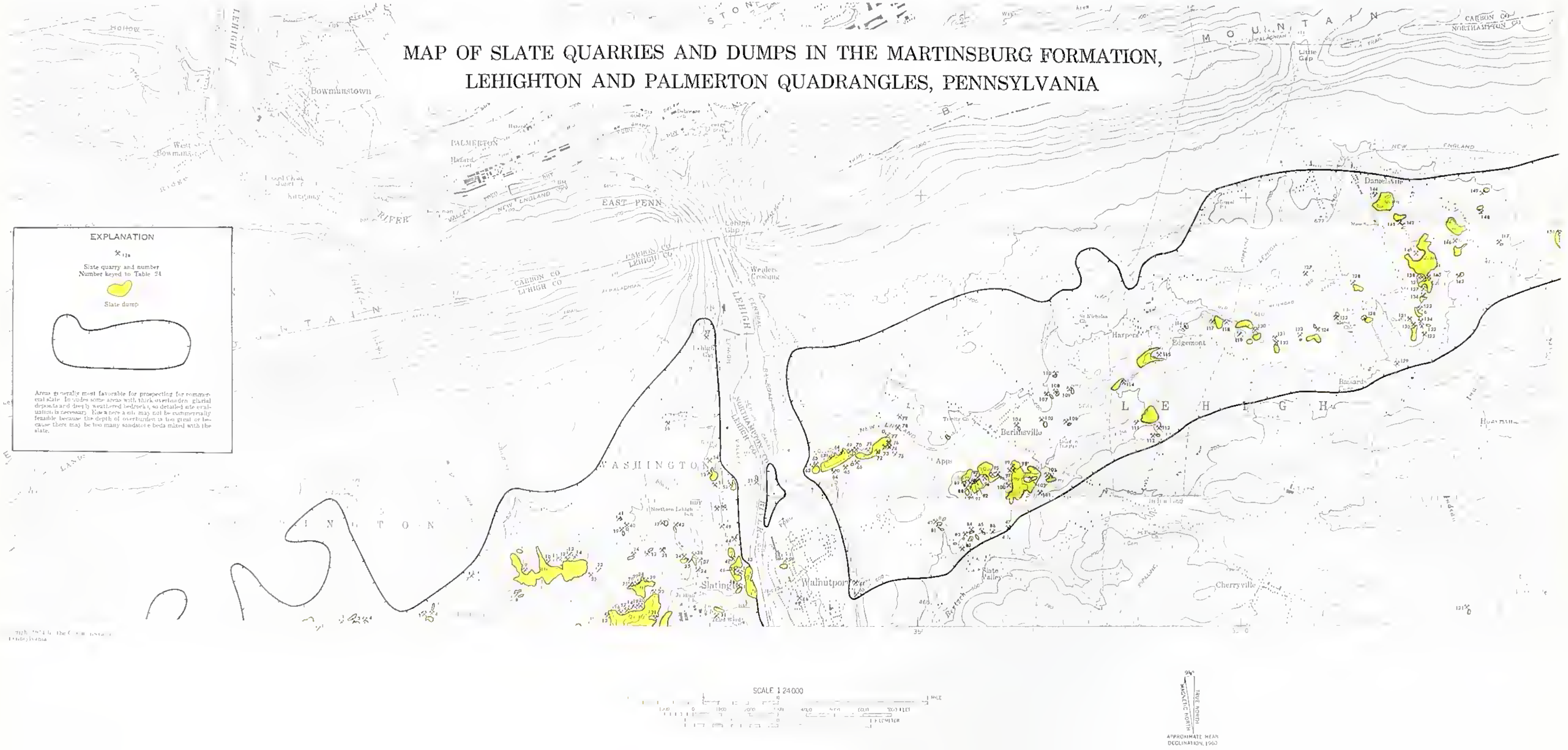
BUREAU OF TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, *State Geologist*

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

Atlas 195cd, Plate 4

# MAP OF SLATE QUARRIES AND DUMPS IN THE MARTINSBURG FORMATION, LEHIGHTON AND PALMERTON QUADRANGLES, PENNSYLVANIA


EXPLANATION
Slate quarry and number
Number keyed to Table 24
Slate dump
Areas generally most favorable for prospecting for commercial slate. Includes some areas with thick overburden, glacial deposits and deeply weathered bedrock, so detailed site evaluation is necessary. Elsewhere a site may not be commercially feasible because the depth of overburden is too great or because there may be too many sandstone beds mixed with the slate.
BLUE MOUNTAIN
Bowmanstown
West Bowmanstown
PALMERTON
EAST PENN
LEHIGH RIVER
CARBON CO
LEHIGH CO
NORTHAMPTON CO
Lehigh Gap
Little Gap
WASHINGTON
Slatington
Walnutport
Berlinsville
Apps
Trinity Ch
Harpers
Edgemont
Danielsville
Slate Valley
Cherryville
L E H I G H
NEW ENGLAND
SCALE 1:24 000
1 MILE
7000 FEET
1 KILOMETER
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1960

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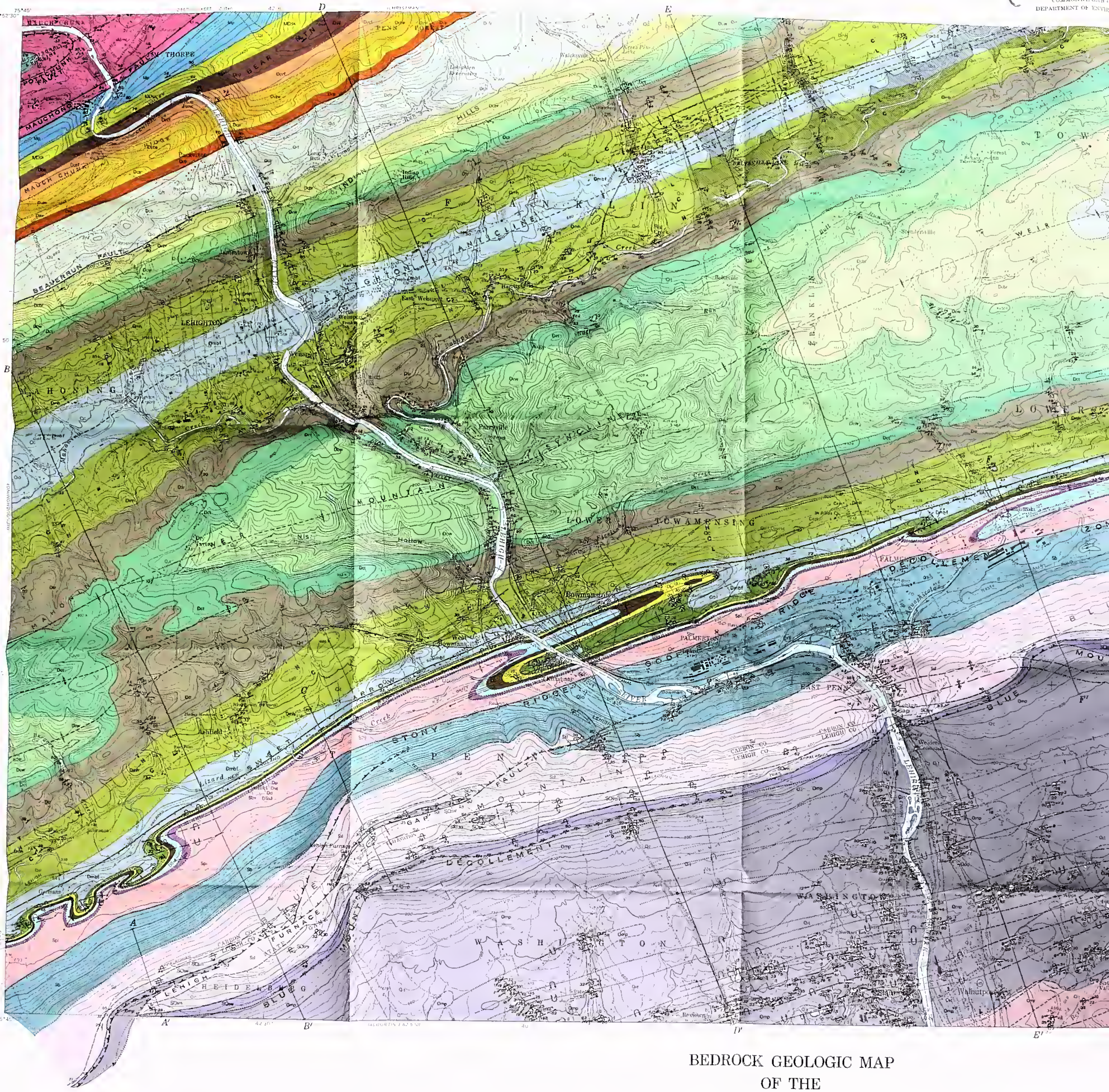

Base map from U.S. Geological Survey Lehighton and Palmerton 7½-minute quadrangles.

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# BEDROCK GEOLOGIC MAP
# OF THE
# LEHIGHTON AND PALMERTON 7½-MINUTE QUADRANGLES, PENNSYLVANIA

by

JACK B. EPSTEIN AND W. D. SEVON

1974

SCALE 1:24000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

Base map from U.S. Geological Survey Lehighton and Palmerton 7½-minute quadrangles.

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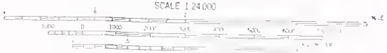
# BEDROCK GEOLOGIC MAP
# OF THE
# LEHIGHTON AND PALMERTON 7½-MINUTE QUADRANGLES, PENNSYLVANIA

by

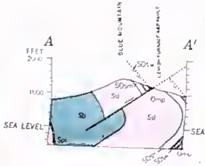
JACK B. EPSTEIN AND W. D. SEVON

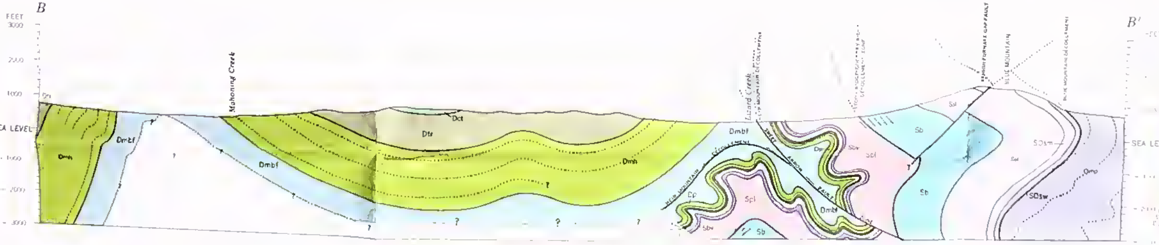
1974

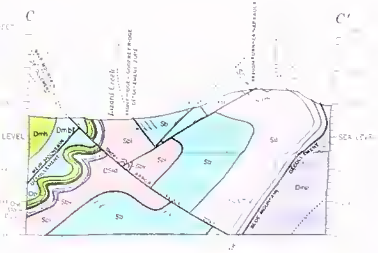
SCALE 1:24 000

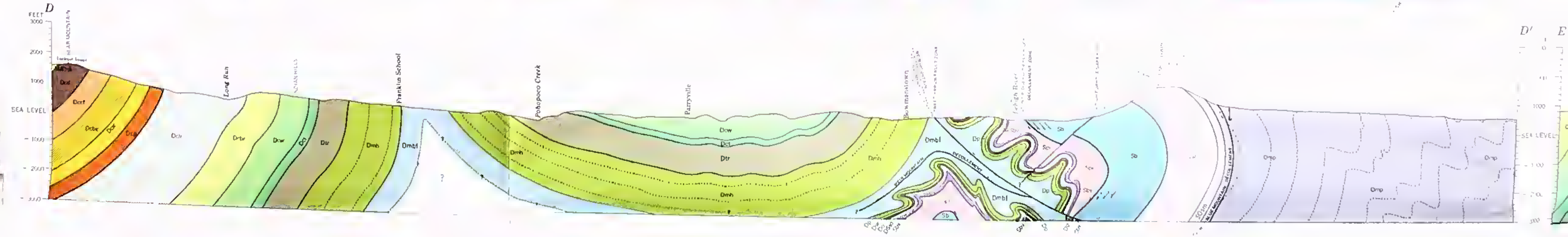


CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL



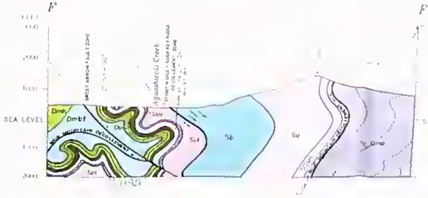


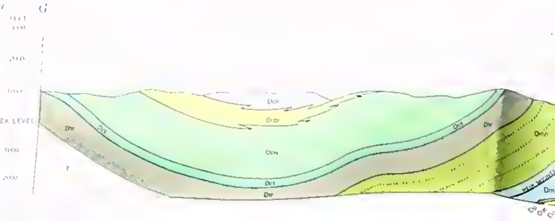




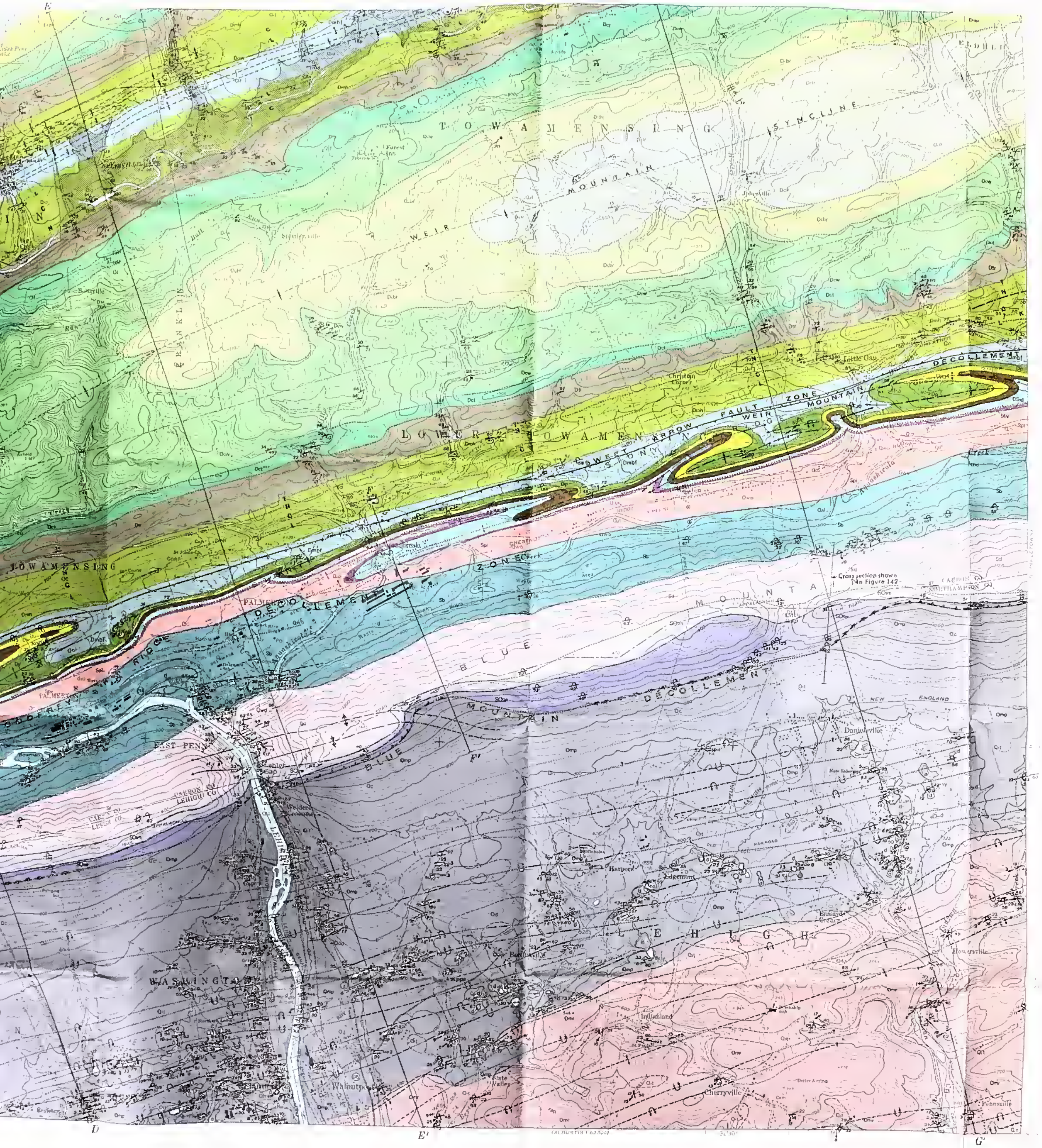
## CROSS SECTIONS

(Scale same as map scale; no vertical exaggeration)





COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES



# BEDROCK GEOLOGIC MAP
# OF THE
# ALMERTON 7½-MINUTE QUADRANGLES, PENNSYLVANIA

by

JACK B. EPSTEIN AND W. D. SEVON

1974

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

APPROXIMATE MEAN DECLINATION, 1960

Albert E. VanOlden, Cartographic Draftsman

Geology based upon field mapping done from 1963-1972

Prepared by the Pennsylvania Geological Survey in cooperation with the U. S. Geological Survey.

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# ND PALMERTON 7½-MINUTE QUADRANGLES, PENNSYLVANIA

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1974

Albert E. VanOlden, Cartographic Draftsman

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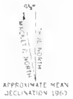
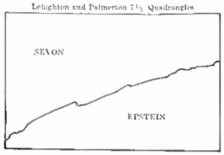
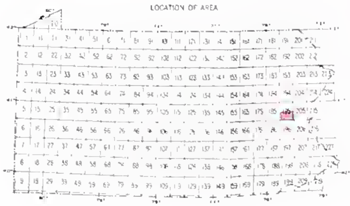
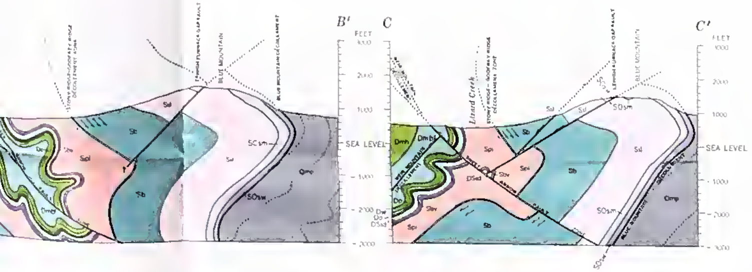
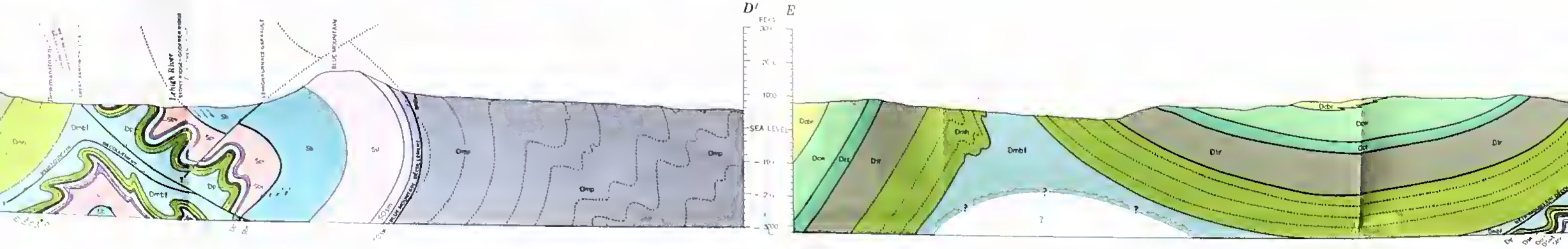
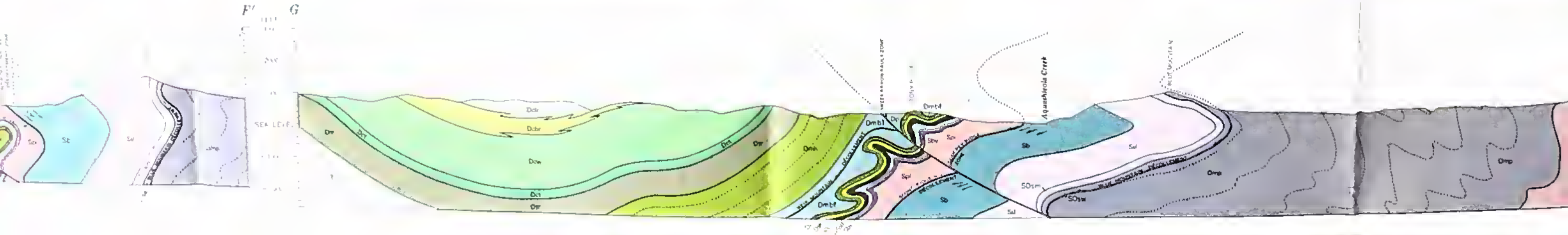


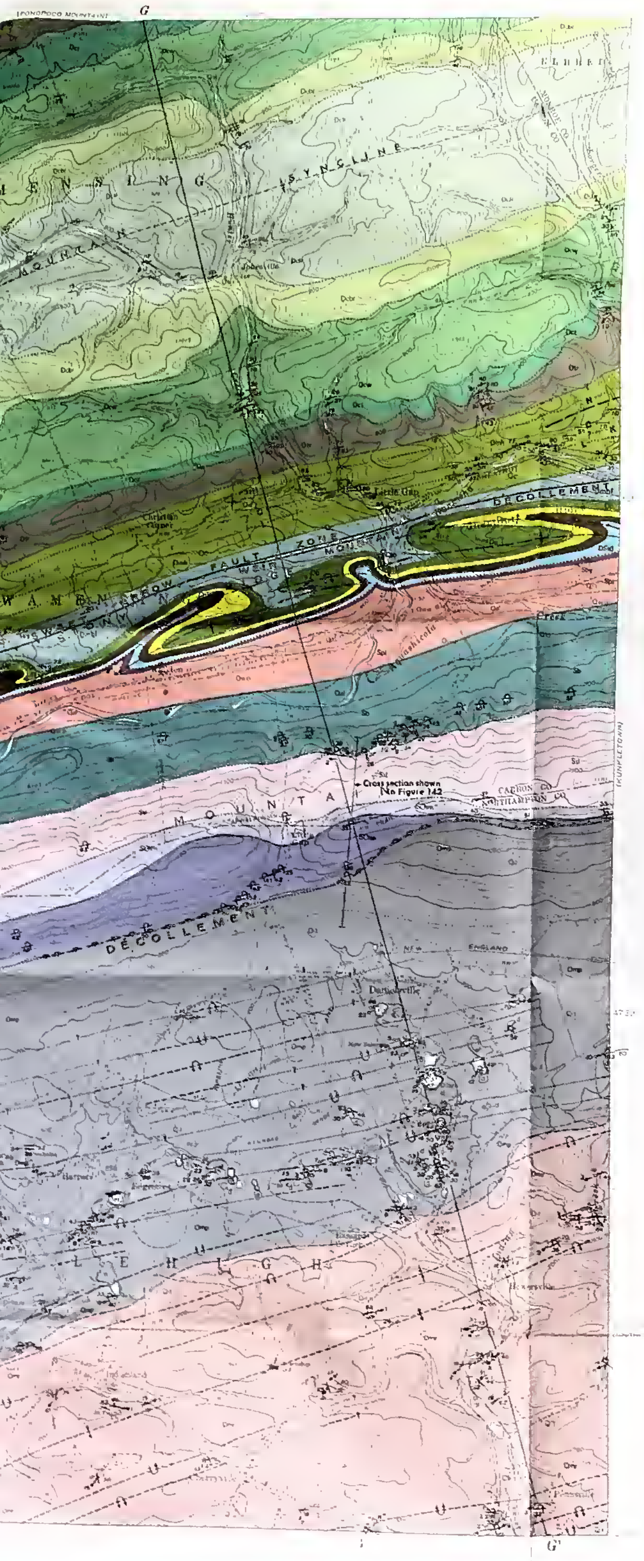








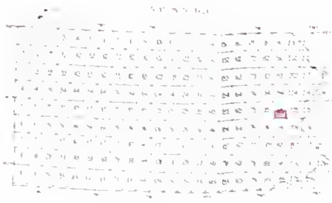




Albert E. VanOlden, Cartographic Draftsman

Geology and new field mapping done in 1965-1972

Prepared by the Pennsylvania Geological Survey in cooperation with the U.S. Geological Survey



## EXPLANATION

QUATERNARY

Holocene

d

**DUMPS**

*Slate dumps south of Blue Mtn; dumps of clinker residue in Palmerton area; dumps from mines in Hazard paint ore along south slope of Stony Ridge*

Ql

**LANDSLIDE DEPOSIT**

*Unsorted mixture of clay, silt, sand, pebbles, and boulders in elongate mound with five feet of surface relief. Located on north slope of Blue Mtn, 1½ mi. east of Lehigh River at Jim Thorpe*

Qc

**COLLUVIUM**

*Sandstone boulders in matrix of pebbles, sand, silt and clay, some boulders on surface; more than 10 feet thick in places*

Qbf

**BOULDER FIELDS**

*Flat-surfaced, matrix-free to matrix-filled accumulations of boulders averaging 1 to 2 feet in diameter; irregular surface in matrix-free areas; thickness unknown.*

Qsr

**SHALE-CHIP RUBBLE**

*Unconsolidated, sub-angular masses of shale chips ¼ to ½ inch long and ⅛ inch thick; clay coatings but no matrix; variable thickness*

Qal

**ALLUVIUM AND FLOODPLAIN DEPOSITS**

*Silt, sand, and gravel deposits in drainage channels, coarse, rounded clasts of variable lithology; thickness of alluvium variable in Lehigh River. Thin, variable deposits in smaller drainage channels, pebbles platy, nonrounded. All generally flat surfaced and currently undergoing erosion, probably as much as 10 feet thick in places.*

Pleistocene

Wisconsinan

Qwo

**WISCONSINAN OUTWASH**

*Brown to yellowish-brown, muddy sand-cobble gravel. Horizontally stratified; well-rounded to subrounded boulders most having a paper-thin weathering rind; more than 60 feet thick in places*

Illinoian(?)

Qio

**ILLINOIAN(?) OUTWASH**

*Reddish-brown, unconsolidated, poorly sorted and stratified sandy gravel; rounded pebbles; some interbedded red clay; variable thickness up to 80 feet.*

Qit

**ILLINOIAN(?) TILL**

*Moderate-reddish-brown, cohesive, unsorted mixture of clay, silt, sand, pebbles, and boulders; variable thickness. May include some stratified drift and pre-Illinoian till. Includes colluvium along north slope of Blue Mountain; variable thickness, probably more than 25 feet in places.*

Pre-Illinoian(?)

Qpo

**PRE-ILLINOIAN(?) OUTWASH (?)**

*Brown to orange, muddy sandy pebble gravel. Horizontally stratified; distinct red color; thickness as much as 9 feet.*

UNCONFORMITY

PENNSYLVANIAN

Pp

**POTTSVILLE FORMATION**

*White sandstones and conglomerates, not exposed; thickness unknown.*

MISSISSIPPIAN

Mmc

**MAUCH CHUNK FORMATION**

*Well-bedded grayish-red siltstones and sandstones; variable bedding thickness; nodular limestone masses in some beds; interbedded gray sandstones and conglomerates and red siltstones in upper 500 feet; 2215 feet thick.*

Mp

**POCONO FORMATION**

*Conglomerates, crossbedded sandstone, and a few siltstones; quartzitic textures; thick massive to thin units; some plant debris; gray colors; 521 feet thick.*

MISSISSIPPIAN-DEVONIAN

MDsk

**SPECHTY KOPF FORMATION**

*Diamictite, pebbly mudstone, orthoquartzitic sandstones, and siltstones; variable unit thicknesses and shapes; silica cementation, gray colors; 545 feet thick.*

UNCONFORMITY ?

DEVONIAN

Upper Devonian

CATSKILL FORMATION

Dcd

**DUNCANNON MEMBER**

*Red sandstones, siltstones, and conglomerates; fining-upward cycles; crossbedded; mud cracks; ripple marks, 965 feet thick.*

Dccf

**CLARK'S FERRY MEMBER**

*Gray to yellowish-gray sandstones and conglomerates; planar and trough cross-stratification and megaripples common; 901 feet thick.*

Dcbe

**BERRY RUN MEMBER**

*Greenish-gray to gray sandstones; some red siltstone beds up to 10 feet thick at top of unit; minor conglomerates; crossbedded; 955 feet thick.*

Dcsr

**SAWMILL RUN MEMBER**

*Greenish-gray to gray sandstones, commonly crossbedded; red siltstones and shales at base and top; 424 feet thick.*

Dcp

**PACKERTON MEMBER**

*Greenish-gray to gray sandstones; minor conglomerates, siltstones, and shales; crossbedding and massive planar bedding common; 416 feet thick.*

Dclr

**LONG RUN MEMBER**

*Alternating gray and red sandstone and red siltstone and shale in fining-upward cycles. 2363 feet thick.*

Dcbr

**BEAVERDAM RUN MEMBER**

*Light-olive-gray siltstones and very fine grained sandstones; massive and fissile beds alternate; crinoid plates, load-cast structures; 365 feet thick.*

Dcw

**WALCKSVILLE MEMBER**

*Alternating greenish-gray sandstone and red siltstone and shale in fining-upward cycles; red color predominates, abrupt lateral color and grain-size changes common, 645 feet thick.*

Dct

**TOWAMENSING MEMBER**

*Gray sandstones and coarse-grained siltstones; many undulatory and scoured surfaces; shale-chip conglomerates; carbonaceous debris; pelecypod molds and burrows; 150 feet thick.*

Dtr

**TRIMMERS ROCK FORMATION**

*Massive and fissile siltstones and shales, very abundant primary structures; fossil fragments and individual shells; 1,054 feet thick.*

Middle Devonian

HAMILTON GROUP

Dmh

**MAHANTANGO FORMATION**

*Massive, nonbedded, medium- to dark-gray, silty shale; prominent cleavage in most places; four thin zones with abundant fossils—*

*(L) Little Gap fossil zone (lower), (K) Kunkletown fossil zone, (C) Centerfield fossil zone, (T) Tully fossil zone (upper). One zone (H) of well-bedded, hard siltstone (Hills Hollow Siltstone); 2100 to 2400 feet thick*

Dmbf

**MARCELLUS FORMATION AND BUTTERMILK FALLS LIMESTONE, UNDIVIDED**

*Marcellus—Grayish-black, fissile, slaty shale; rare fossils; calcareous zone up to 25 feet thick in lower part; Tioga bentonite at base, about 500 feet thick*

*Buttermilk Falls—Upper part, deeply leached argillaceous, fossiliferous limestone with layers of black chert; some micaceous clay, 24 feet thick. Middle part: Hazard paint ore; hard, slaty limestone, fossiliferous, up to 4 feet thick. Lower part gray to black, massive slaty shale, 6 feet thick or less. At surface only in north slope of Stone, Stony, and Chestnut Ridges*

UNCONFORMITY ?

Dp

**PALMERTON FORMATION**

*Massive, white, variably indurated with silica, fine- to coarse-grained sandstone; lacks bedding; well-jointed; forms crest of Stone, Stony, and Chestnut Ridges; 100 feet thick.*

Lower Devonian

Dse

**SCHOHARIE AND ESOPUS FORMATIONS, UNDIFFERENTIATED**

*Well-bedded, very fine to coarse-grained, gray to olive-gray, hard siltstones; poorly fossiliferous with contorted crossbed structures in lower part (Esopus); red hematite-rich bed near middle; fossiliferous in upper part (Schoharie), 18 to 76 feet thick*

UNCONFORMITY ?

Do

**ORISKANY GROUP (RIDGELEY FORMATION AND SHRIVER CHERT) AND NEW SCOTLAND FORMATION, UNDIVIDED**

*Ridgeley—White quartz sandstone and fine-grained pebble conglomerate with abundant brachiopod molds; variable silica cementation; 8 to 50 feet thick*

*Shriver—Weathered white to orange chert, sandstone, and conglomerate; brachiopods; about 25 feet thick.*

*New Scotland—Weathered white to light-brown clay, chert, and silty to arenaceous clay; no exposures, about 20 to 40 feet thick.*

DEVONIAN-SILURIAN

DSsd

**STORMVILLE MEMBER OF THE COEYMANS FORMATION AND DECKER FORMATION, UNDIVIDED**

*Stormville—Weathered, partly conglomeratic sandstone and minor shale and siltstone; about 50 feet thick.*

*Decker—Fossiliferous limestone, siltstone, sandstone, and shale. Includes sandstone, shale, and siltstone of the Andreas Red Beds at the top; about 80 to 90 feet thick.*

SILURIAN

Upper Silurian

Sbv

**BOSSARDVILLE LIMESTONE**

*Laminated to thin-bedded limestone and lesser shale; mud cracks; fossiliferous; about 100 feet thick.*

Sp

**POXONO ISLAND FORMATION**

*Laminated to finely bedded dolomite, limestone, and shale; red shale and siltstone in lower part, mud cracks; sparsely fossiliferous; thickness extremely variable, averages about 550 feet.*

Middle Silurian

Sb

**BLOOMSBURG RED BEDS**

*Red siltstone, shale, and sandstone; fining-upward cycles, mud cracks, crossbedded; laminated to thick bedded, about 1,500 feet thick.*

Lower Silurian

SHAWANGUNK FORMATION

Ssl

**LIZARD CREEK MEMBER**

*Gray and minor reddish sandstone, siltstone, and shale; minor nodules of collophane, siderite, and chlorite; Lingula fragments; 1,225 feet thick.*

SILURIAN-ORDOVICIAN

SOsm

**MINSI MEMBER**

*Gray planar-bedded and crossbedded partly conglomeratic quartzite; scattered silty shale, quartz pebbles as much as 2 inches long, 140 to 225 feet thick.*

SOsw

**WEIDERS MEMBER**

*Gray planar-bedded and crossbedded conglomerate and quartzite; pebbles as much as 6 inches long; 50 to 220 feet thick.*

UNCONFORMITY

ORDOVICIAN

Upper Ordovician

MARTINSBURG FORMATION

Omp

**PEN ARGYL MEMBER**

*Gray, thin- to thick-bedded, evenly bedded, calcareous slate, rhythmically interbedded with carbonaceous slate and graywacke; 5,000 to 6,000 feet thick.*

Middle Ordovician

Omr

**RAMSEYBURG MEMBER**

*Gray slate and graywacke, thin- to thick-bedded; about 2,550 feet thick; base not exposed in mapped area.*

Omb

**BUSHKILL MEMBER**

*Thin-bedded slate and graywacke; shown in section only.*

## SYMBOLS

Bedrock     Surficial

Contact

Dashed where approximately located; short dashed where inferred; dotted where concealed.

Inclined     Overturned

Décollement

Sawteeth on upper plate. Dashed where approximately located, dotted where concealed.

Thrust fault

Sawteeth on upper plate. Dashed where approximately located, short dashed where inferred, dotted where concealed.

U
D

High-angle fault

Dotted where concealed. U, upthrown side; D, downthrown side.

Anticline

Showing trace of axial surface and direction of plunge. Dashed where approximately located, short dashed where inferred, dotted where concealed.

Syncline

Showing trace of axial surface and direction of plunge. Dashed where approximately located, short dashed where inferred; dotted where concealed.

Anticline

Showing trace of crestal plane and direction of plunge. Dashed where approximately located; short dashed where inferred; dotted where concealed.

Syncline

Showing trace of trough plane and direction of plunge. Dashed where approximately located; short dashed where inferred, dotted where concealed.

Overturned anticline

Showing trace of axial surface and direction of dip of limbs and plunge. Dashed where approximately located, short dashed where inferred; dotted where concealed.

Overturned syncline

Showing trace of axial surface and direction of dip of limbs and plunge. Dashed where approximately located, short dashed where inferred; dotted where concealed.

Antiformal syncline

Southeast limb overturned, northwest limb rotated more than 180°.

Showing trace of axial surface and direction of dip of limbs and plunge. Dashed where approximately located, short dashed where inferred, dotted where concealed.

Synformal anticline

Northwest limb overturned, southeast limb rotated more than 180°

Showing trace of axial surface and direction of dip of limbs and plunge. Dashed where approximately located; short dashed where inferred; dotted where concealed.

35 Inclined     Vertical     ⊕ Horizontal

45 Rotated more than 180°     35 Overturned

Strike and dip of beds

35 Inclined     Vertical

Strike and dip of slaty cleavage

Inclined     Horizontal

Bearing and plunge of intersection of bedding and cleavage

Strike and dip of slip cleavage

Bearing and plunge of intersection of slaty cleavage and slip cleavage

Bearing and plunge of bedding-plane slickensides

Inclined     Vertical

Strike and dip of joints

Shown only in rocks younger than Oriskany Group.

Water well or exploratory drill hole referred to in text

Abandoned paint-ore mine or prospect

A ——— A'

Line of cross section

Albert E. VanOlden, Cartographic Draftsman

Geology based upon field mapping done from 1963-1972

Prepared by the Pennsylvania Geological Survey in cooperation with the U.S. Geological Survey.

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35 Inclined Vertical Horizontal

45 Rotated more than 180° 25 Overturned

**Strike and dip of beds**

Inclined Vertical

**Strike and dip of slaty cleavage**

Inclined Horizontal

**Bearing and plunge of intersection of bedding and cleavage**

**Strike and dip of slip cleavage**

**Bearing and plunge of intersection of slaty cleavage and slip cleavage**

**Bearing and plunge of bedding-plane slickensides**

Inclined Vertical

**Strike and dip of joints**

Shown only in rocks younger than Oriskany Group.

6

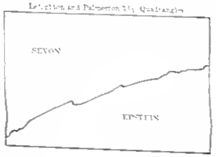
**Water well or exploratory drill hole referred to in text**

**Abandoned paint-ore mine or prospect**

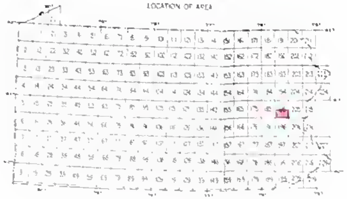
A A′

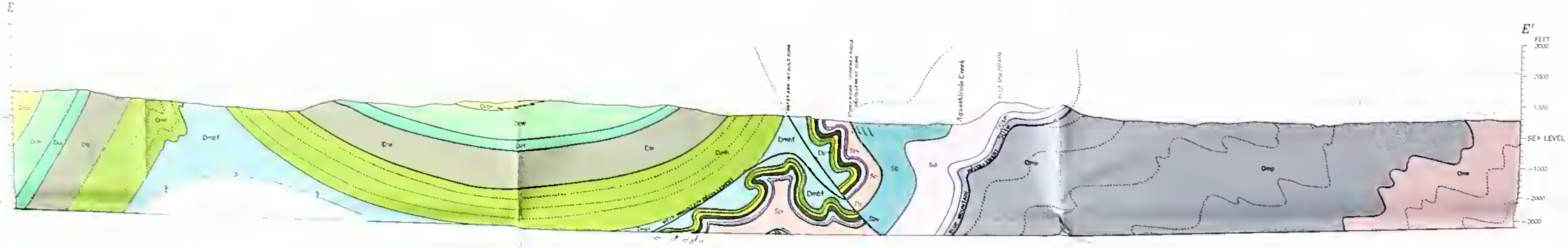
**Line of cross section**

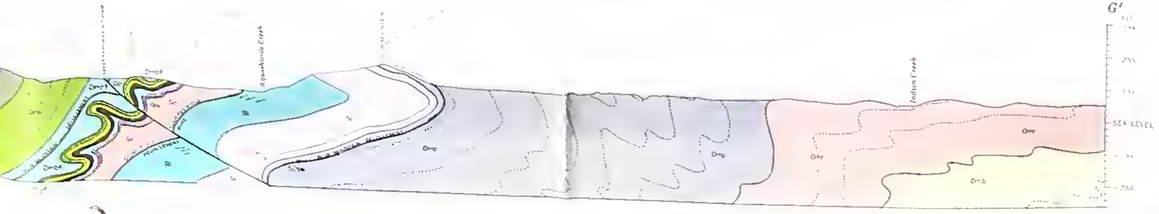
Lehighton and Palmerton 15′ Quadrangles



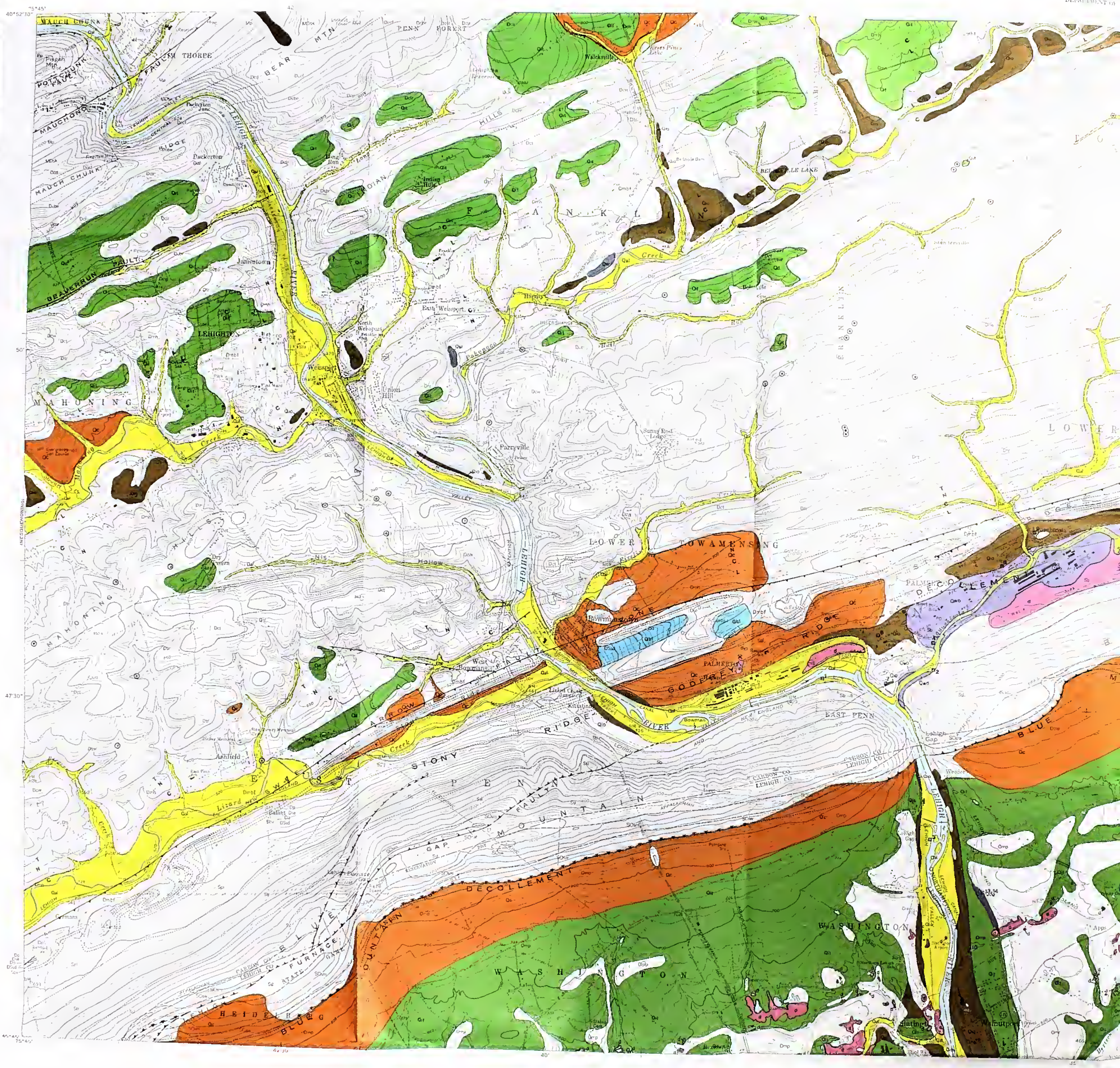
LOCATION OF AREA







BUREAU OF TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, *State Geologist*



Base map from U.S. Geological Survey Lehighton and Palmerton 7½-minute quadrangles

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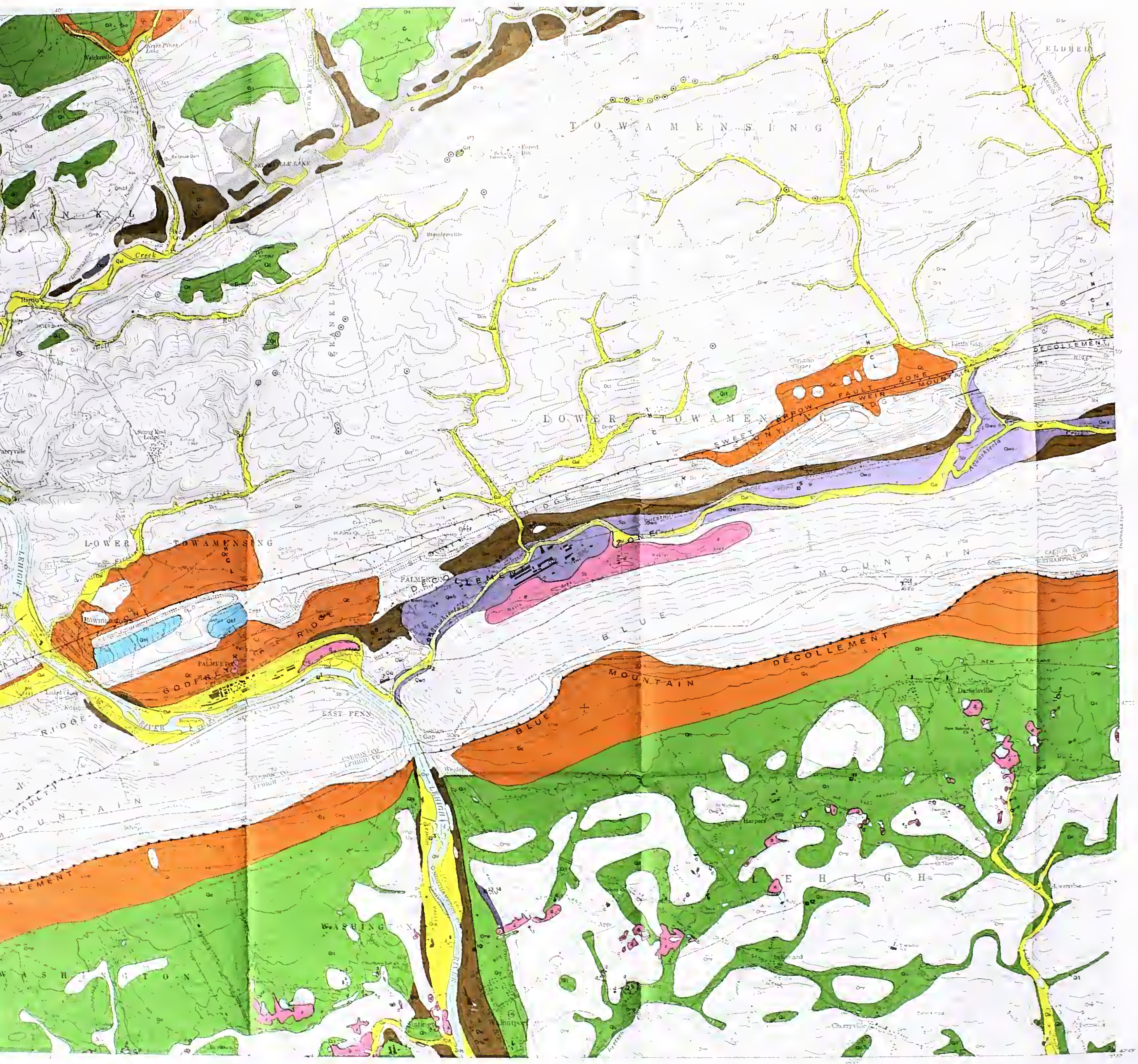

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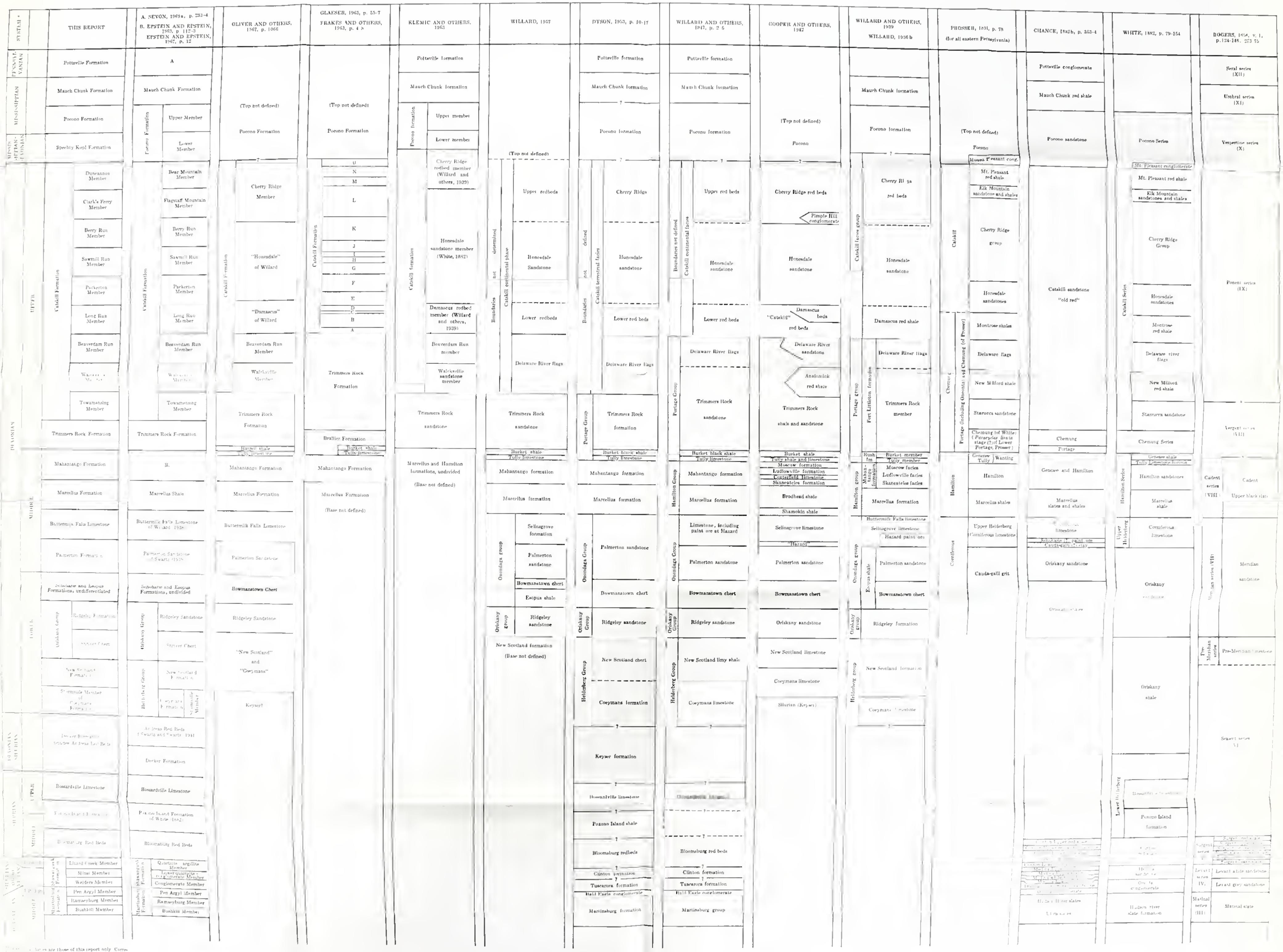

Names are those of this report only. Correlations between formations and members are lithologic correlations, not time-stratigraphic correlations.

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# STRATIGRAPHIC CORRELATION CHART FOR THE LEHIGHTON AND PALMERTON QUADRANGLES, PENNSYLVANIA